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FURTHER INVESTIGATION INTO THE CAUSES OF VARIABILITY IN AIRCRAFT TURBINE ENGINE EMISSION MEASUREMENT

Anthony F. Souza

Scott Environmental Technology, Incorporated

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Environmental Protection Agency

November 1975

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Mobile Source Air Pollution Control
Emission Control Technology Division
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16. ABSTRACT

Under Environmental Protection Agency Contract Number 68-03-0410, Scott Environmental Technology, Inc., studied the causes of variability in aircraft turbine engine emission measurements. A technique for mass flow weighting of a detailed exhaust traverse data was developed. Mass flow weighted emissions data of a modified TF-30 engine were calculated and compared to other techniques used for calculating exhaust emission rates of gas turbine engines. Ambient concentrations of exhaust related gases in and around an engine test cell were monitored during gas turbine engine operation. The effect of ambient concentrations on emission measurements is evaluated. A probe manipulator capable of interchanging and rotating three multiple hole exhaust gas sampling probes was designed, fabricated and tested. Using this probe manipulator, test probe designs were evaluated and compared during one continuous engine run eliminating engine operating conditions as a test variable.

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Contract No. 68-03-0410

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This report was furnished to the Environmental Protection Agency by Scott Environmental Technology, Inc., Plumsteadville, Pennsylvania 18949, in fulfillment of Contract No. 68-03-0410. The contents of this report are reproduced herein as received from Scott Environmental Technology, Inc. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

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ABSTRACT

Under Environmental Protection Agency Contract Number 68-03-0410, Scott Environmental Technology, Inc. has furthered an investigation into the causes of variability in turbine engine emission measurements. The primary objective of the overall program was the development of reliable, accurate test procedures for use in measuring emissions from aircraft turbine engines. A comprehensive study of the variability due to the instrument system sampling probe, ambient conditions and engine parameters was performed under the original contract which pointed out the need for more work in the area of exhaust sampling technique. Under this contract, a technique for mass flow weighting of a detailed exhaust traverse data was developed. Mass flow weighted emissions data of a modified TF-30 engine were calculated and compared to other techniques used for calculating exhaust emission rates of gas turbine engines.

Ambient concentrations of exhaust related gases in and around an engine test cell were monitored during gas turbine engine operation. The effect of ambient concentrations on emission measurements is evaluated.

A probe manipulator capable of interchanging and rotating three multiple hole exhaust gas sampling probes was designed, fabricated and tested. Using this probe manipulator, test probe designs were evaluated and compared during one continuous engine run eliminating engine operating conditions as a test variable. The results of tests of three probe designs are presented.

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FORWARD

This report was prepared by Scott Environmental Technology, Inc. under Environmental Protection Agency contract number 68-03-0410. The work reported herein was administered under the direction of the Emission Control Technology Division, Office of Air and Water Pollution, Environmental Protection Agency with Mr. Gary Austin serving as Project Officer. This report covers work performed from January 1974 through November 1974. The author of this report is Anthony F. Souza.

The program described in this report was performed with the cooperation of the Federal Aviation Agency at the National Aviation Facilities Experimental Center, Atlantic City, New Jersey, and the author wishes to acknowledge the special efforts of Mr. Gerald Slusher and Mr. Stephen Imbrogno of the FAA.

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1.0 INTRODUCTION

This report describes the work performed by Scott Environmental Technology, Inc. under Environmental Protection Agency contract number 68-03-0410. Variability in aircraft turbine engine emission measurements was studied in a previous contract. In this contract,[1] variability arising from exhaust sampling techniques was further studied. The primary objective of the overall program was the development of reliable, accurate test procedures for use in measuring emissions from aircraft turbine engines. A comprehensive study of the variability due to the instrument system sampling probe, ambient conditions and engine parameters was performed under the original contract which pointed out the need for more work in the area of exhaust sampling technique.

Ambient concentrations of exhaust gases in and around the engine test cell were measured during engine tests and their effect on the measurement of exhaust emissions was evaluated.

Detailed exhaust traverse data from a modified P&W TF30 engine were analyzed to determine the effect of mass flow weighting of the measured emission concentrations on the calculation of emissions.

A probe manipulator capable of interchanging and rotating three experimental multi-point probes was designed, fabricated and tested. With this probe manipulator, test probes were evaluated during continuous engine runs, eliminating the engine operating conditions as an uncontrolled test variable.

1.1 THE TEST ENGINE

The gas turbine engine used for all the tests described in this report was a Pratt and Whitney model TF30-P1 dual spool mixed flow engine owned by the Federal Aviation Administration. The engine was operated at the FAA's National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey.

The engine was modified by removing the afterburner assembly including spray bars, fuel manifolds, and flame holder and installing a fixed area exhaust nozzle in the fashion of commercial engines. The modified TF30 engine produced 11,000 pounds thrust, had a compressor pressure ratio of 17:1 and was equipped with eight can-annular combustion chambers. The engine incorporates a front fan, airflow ratio approximately 1:1, which diverts air through an annular duct that forms the outer shell of the engine. Similar to the JT8D, the bypass air duct terminates downstream of the turbine and P7 station. Three struts (120°) are utilized in the core exhaust stream to support the turbine.

Engine total time at the time of the tests was approximately 300 hours and the time since overhaul was 100 hours.

The engine was operated in an open sea-level gas turbine test stand with provision for the measurement of all engine operating parameters including thrust. Four exhaust sampling probes were mounted in the exhaust nozzle to provide a reference exhaust emission sample independent of other exhaust emission probes and experiments. These four probes were designed to sample primarily exhaust from the core engine.

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2.0 AMBIENT CONCENTRATIONS OF POLLUTANTS IN GAS TURBINE TEST CELLS

Pollutant concentrations present in the ambient air in the test cell can have an effect on the emission rates calculated from test on gas turbine engines. This is more likely to be significant for tests on turbines than other types of engines or stationary sources because of their very high air/fuel ratio. For example, the average carbon dioxide concentration emitted by a mixed flow turbine at idle is approximately 0.6%. The typical background at the Atlantic City test site is 0.04% which is 7% of the exhaust value.

In order to determine the magnitude of the effect of ambient levels on emission rates calculated in this program, the ambient concentration levels of the measured pollutants in and near the test cell were monitored during four TF30 engine test periods. Carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THC), nitric oxide (NO), and total oxides of nitrogen (NO_x) were measured at four test points. Test point 1 was located outside the test cell air inlet baffle about six feet above ground level. Test point 2 was located at the turbine engine air inlet screen approximately one foot in from the bellmouth edge. Test points 3 and 4 were located at the turbine engine exhaust plane on the engine centerline about three inches outside of the jet nozzle. Test point 3 was on the right side (facing forward) located downstream of the engine oil sump breather, and test point 4 was on the left side.

The ambient pollutant concentrations measured in the four tests are plotted as a function of engine running time in Figures 2-1 through 2-4. The corresponding engine power settings and reference test run reading numbers are also indicated on the plots.

2.1 AMBIENT CARBON DIOXIDE VALUES

Of the data taken at the four sampling points, the values at Point 2 are of the greatest significance to emissions because they are representative of the inlet air entering the turbine. The CO_2 gas analyzer used for background measurements was operated at 0-1.5% CO_2 full scale. Nearly all of the inlet CO_2 readings were from 0.03 to 0.04%. This indicates that the inlet air CO_2 was close to the normal atmospheric

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Figure 2-1

Ambient Air Measurements April 25, 1974

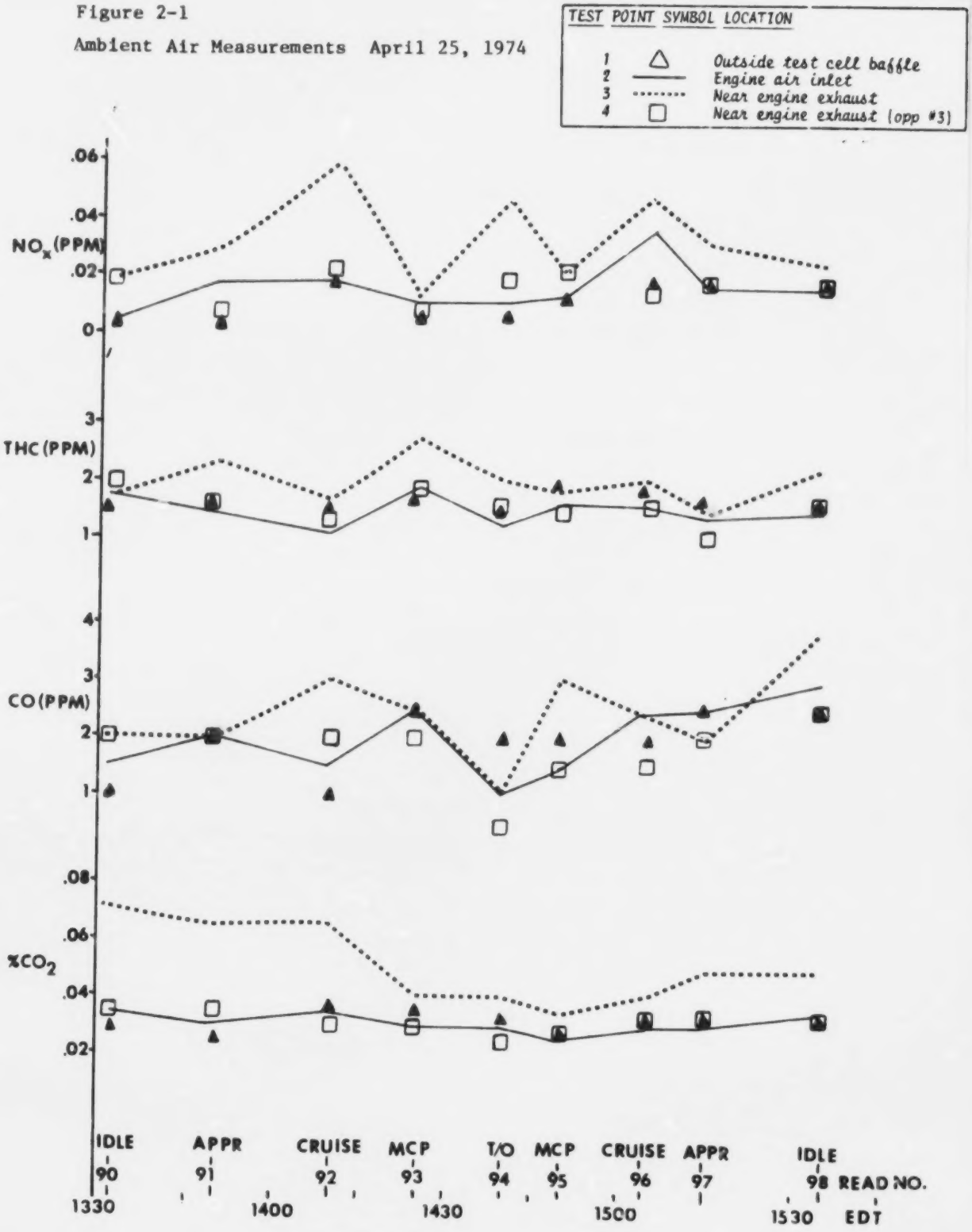

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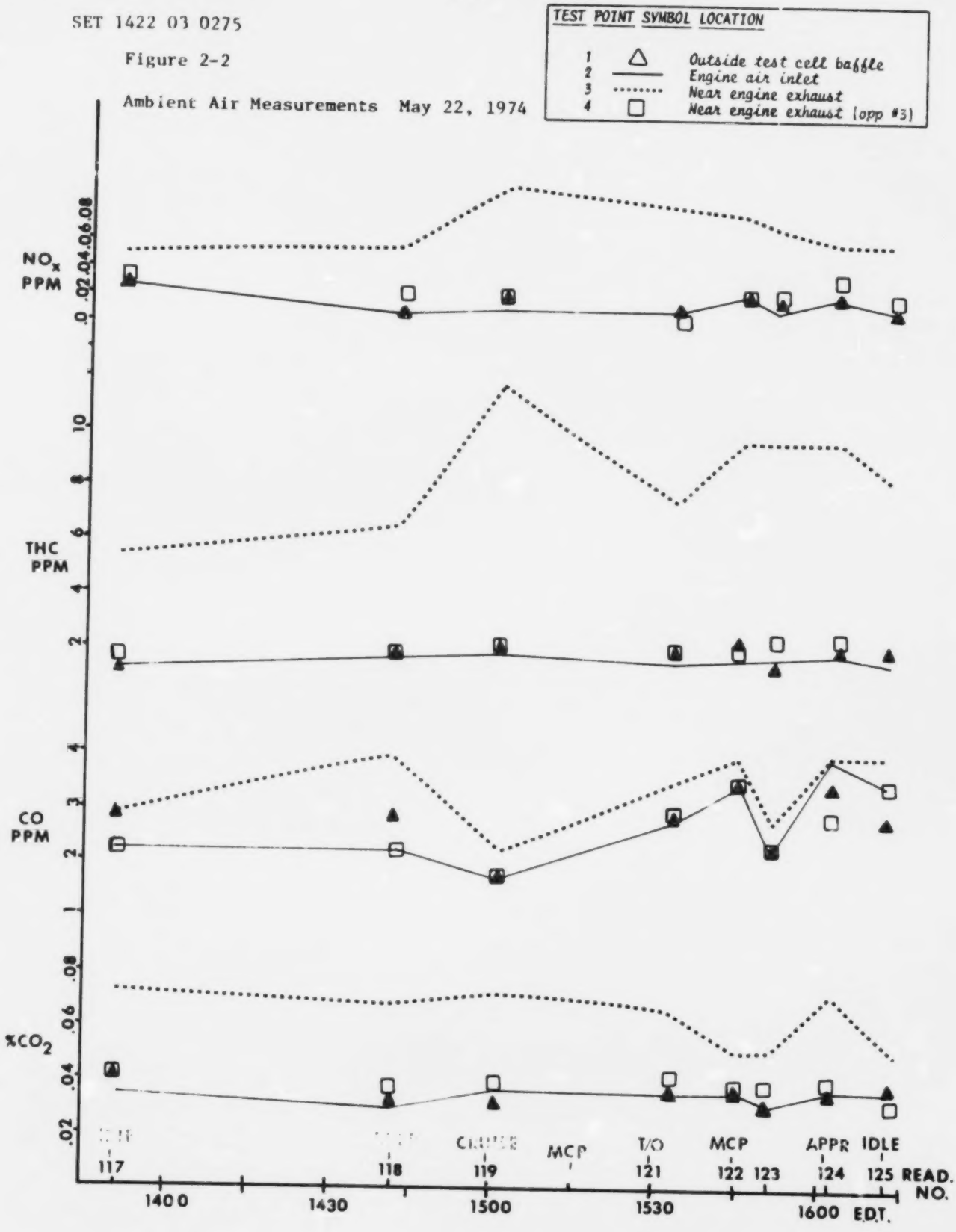
Figure 2-2

Ambient Air Measurements May 22, 1974


TEST POINT SYMBOL LOCATION
1 Outside test cell baffle
2 Engine air inlet
3 Near engine exhaust
4 Near engine exhaust (opp #3)
NOx PPM
.0 .02 .04 .06 .08
THC PPM
2 4 6 8 10
CO PPM
1 2 3 4
%CO2
.02 .04 .06 .08
117 118 119 121 122 123 124 125
IDLE MCP T/O MCP APPR IDLE
READ. NO.
1400 1430 1500 1530 1600 EDT.

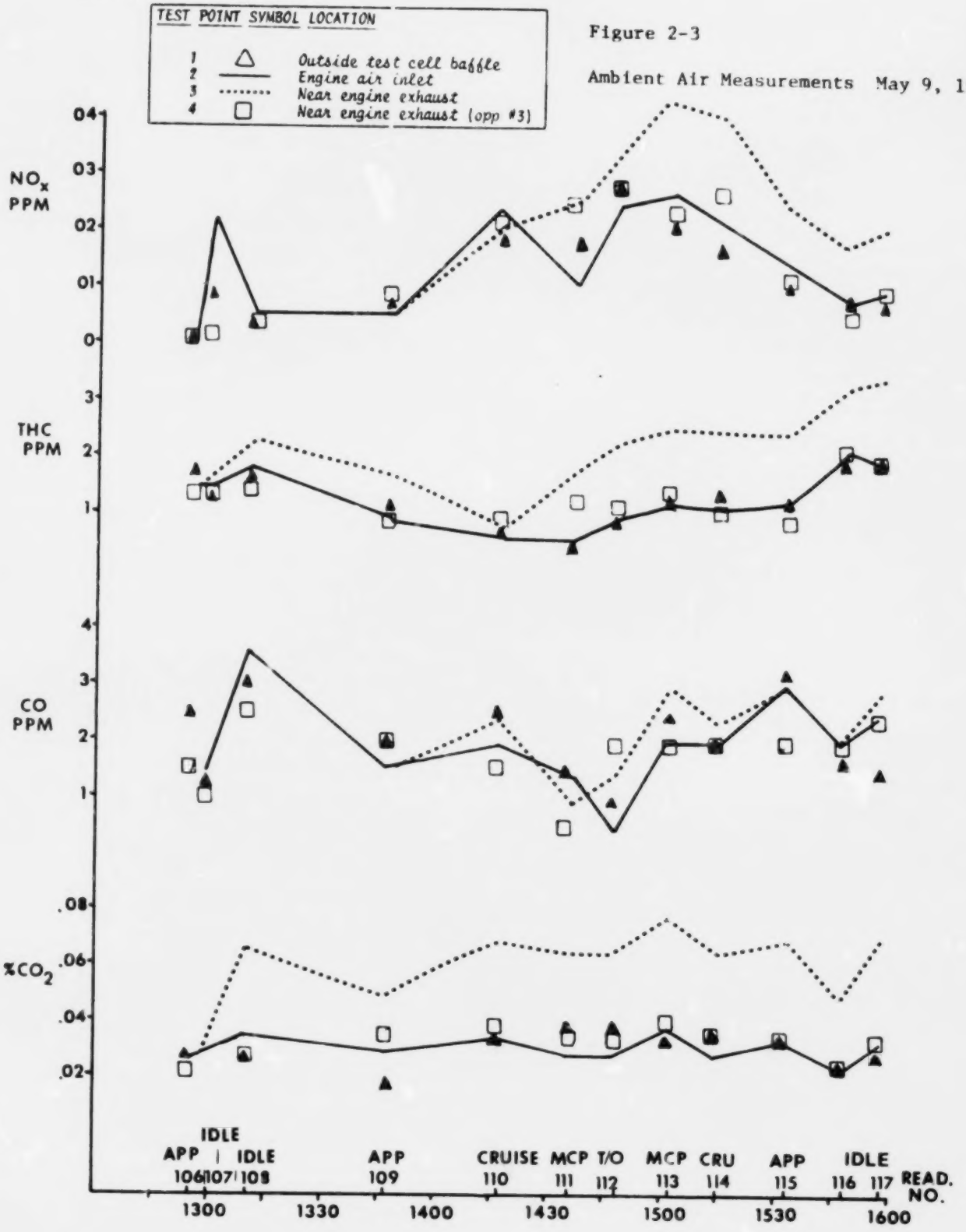


Figure 2-3

Ambient Air Measurements May 9, 1974

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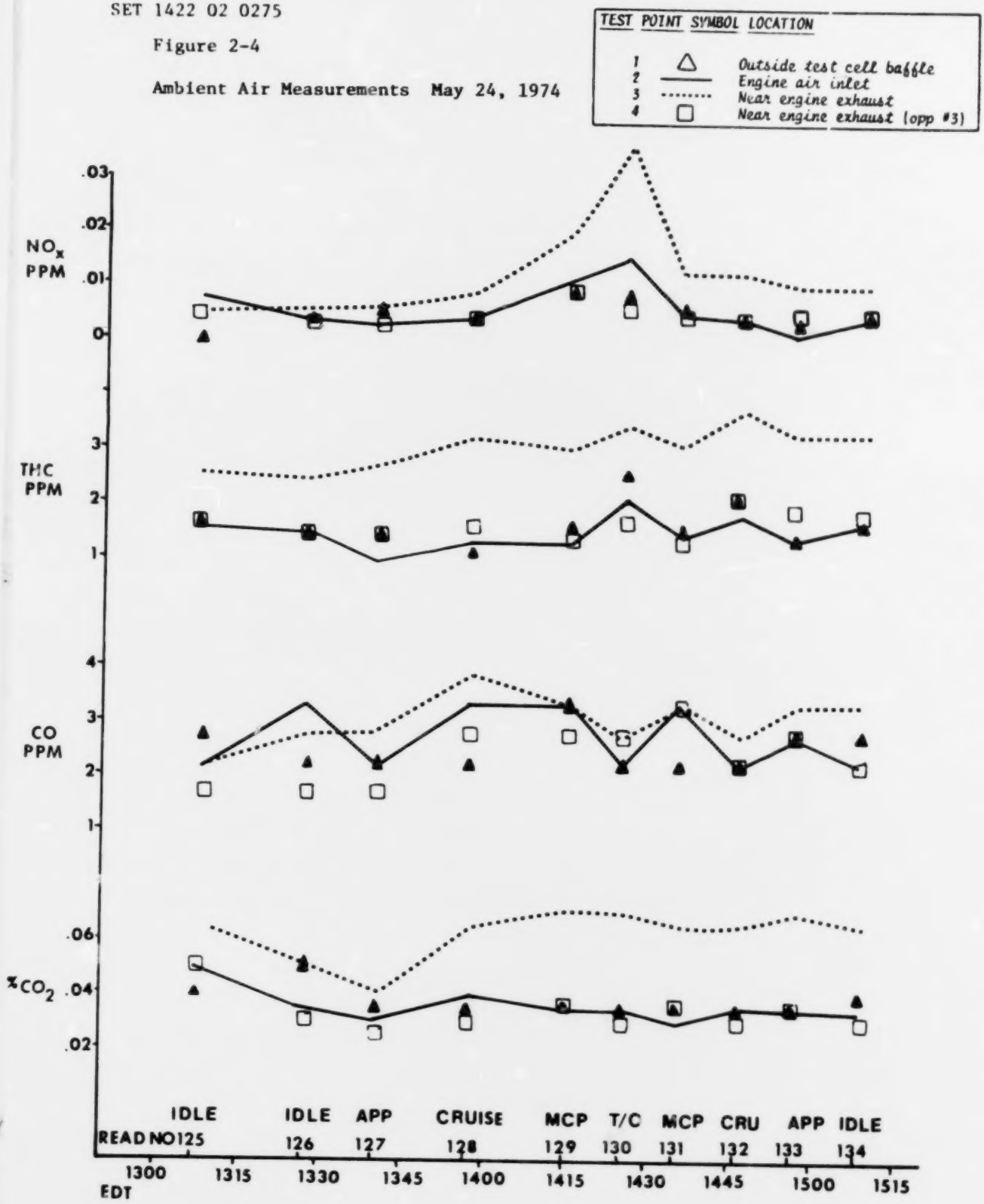
Figure 2-4

Ambient Air Measurements May 24, 1974



background and it was not being contaminated by engine exhaust or other pollutant sources. However, the carbon dioxide level near the exhaust plane (Point 3) was higher than the background level and ranged up to 0.08%. A visible plume from the oil breather passed in the vicinity of test point 4. There evidently is an external influencing factor such as contamination from the engine breather or exhaust recirculation. Point 4, which was also located near the exhaust plane, but on the opposite side gave values of carbon dioxide very close to the engine inlet and outside ambient levels in all tests.

The high CO_2 values at Point 3 demonstrate that it is not desirable to measure background levels in the vicinity of the nozzle because the air may be contaminated and the readings will not necessarily represent the true background levels at the engine inlet.

2.2 CARBON MONOXIDE

Carbon monoxide background concentrations ranged from 1 to 4 ppm with most values between 2 and 3 ppm. Data at Point 3 were frequently 1 ppm higher than at the inlet. One point that must be considered in treating background CO is that some of the CO will be burned to CO_2 as the air passes through the engine combustion zones. The best location for the measurement of background levels is at the air inlet to the engine.

2.3 TOTAL HYDROCARBONS

The total hydrocarbons at the inlet were ordinarily in the 1 to 2 ppm range typical of ambient air. The hydrocarbons measured at Point 3 tended to increase with time and approached 10 ppm. As with carbon monoxide, some combustion of background hydrocarbons will occur as the air passes through the engine.

2.4 NITROGEN OXIDES

The nitrogen oxides concentration at the engine inlet was usually less than 0.1 ppm except in the tests of May 9, 1974, when it ranged up to 0.25 ppm. The levels at Point 3 ranged up to more than double the inlet levels.

2.5 EFFECT OF BACKGROUND POLLUTANT CONCENTRATIONS ON CALCULATED EMISSION RATES

Turbine emission rates are generally expressed as pounds per 1000 pounds of fuel calculated using a carbon balance technique. This calculation procedure is explained in detail in Reference 2. The simplified equations for CO, THC and NO_x are as follows for W expressed in pounds per 1000 pounds of fuel. CO, THC, and NO_x are expressed in parts per million (ppm) and CO_2 is expressed in percent (%).

$$W_{CO} = \frac{0.20\ (CO)}{\frac{CO}{10^4} + CO_2 + \frac{THC}{10^4}}$$

$$W_{HC} = \frac{0.10\ (THC)}{\frac{CO}{10^4} + CO_2 + \frac{THC}{10^4}}$$

$$W_{NO_x} = \frac{0.329\ (NO_x)}{\frac{CO}{10^4} + CO_2 + \frac{THC}{10^4}}$$

The effect of typical ambient levels as found in this program on calculated emission rates for a TF-30 engine is shown in Table 2-1. This table compares the emission rates calculated after correcting exhaust pollutant concentrations for inlet background concentrations to those calculated from exhaust concentrations only. It is apparent that significant errors in calculated emission rates, both positive and negative, are likely to occur if inlet concentrations are neglected. The test cell is located in a non-urban area, and it is also relatively remote from other test cells and other sources of pollutants. The errors due to background would tend to be even larger where test cells are located closer to pollutant sources.

Based on these findings, it is strongly recommended that pollutant measurements be made at the engine inlet during each test run. Where high concentrations of carbon monoxide or hydrocarbons are present at the inlet, an estimate of the amounts of these constituents burned in the engine must be made. A basis for the estimate could be obtained by introducing a known amount of an individual low molecular weight hydrocarbon at the inlet and measuring its concentration in the exhaust.

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TABLE 2-1 THE EFFECT ON CALCULATED EMISSION RATES OF CORRECTION FOR BACKGROUND POLLUTANT LEVELS

Typical Exhaust and Background Concentrations Found in Tests of TF-30 Engine

Operating Condition	Exhaust Conc. CO_2 %	CO ppm	THC ppp-C	NO_x ppm	Background Conc. (at air inlet) CO_2 %	CO ppm	THC ppm-C	NO_x ppm
Idle	0.58	163	71	3.4	0.04	3	2	0.1
Approach	0.85	67	13	13	0.04	3	2	0.1
Max.Cont.Power	1.35	18	11	45	0.04	3	2	0.1

Emission Rates (#/1000 # Fuel)

Operating Condition	CO as read	CO corr.*	CO Δ,%	THC as read	THC corr.*	THC Δ,%	NO_x as read	NO_x corr.*	NO_x Δ,%
Idle	54	57	+6	11.7	12.3	+5	1.85	1.98	+4
Approach	15.6	15.6	0	1.5	1.3	-11	5.0	5.2	+4
Max.Cont.Power	2.7	2.3	-14	0.8	0.7	-16	10.9	11.3	+4

*Corrected concentration = exhaust conc. - background conc.

3.0 MASS FLOW WEIGHTED TRAVERSE DATA

In the previous investigation of variability in turbine engine emission measurements (Contract No. 68-01-0443), a traversing probe was used to obtain concentration readings at 177 points in the exhaust nozzle plane of a JT8D engine. The concentrations at each point were then averaged to obtain a concentration representative of the total exhaust stream. Later the data were compared to data obtained using various mixing probes. It was suggested that part of the differences found between traverse and mixing probe data was due to the fact that mass flow rates were not used in averaging the traverse data. That is, when the data for each of the 177 points were averaged, there was an inherent assumption that the mass flow at each point was the same. No mass flow data were available for the JT8D, so the magnitude of the error caused by the assumption could not be determined.

The method approved by the Environmental Protection Agency for measuring mass emission rates from a source with non-uniform cross sectional concentrations is to measure the concentration at a large number of points representing centers of equal area and to simultaneously measure flow parameters. The mass emission rate for each area is the product of this concentration and mass flow. The total emission rate is the sum of the rates for each area.

3.1 DETERMINATION OF MASS FLOW RATES FOR A TF-30 ENGINE

The differences between emission rates calculated by arithmetic averaging of traverse data points and those obtained from mass flow weighted data were investigated for a TF-30 engine. The required data included total pressure, static pressure and total temperature profiles for the exhaust plane of the TF-30 as well as pollutant concentration measurements.

3.1.1 Mass Flow Measurements

The data required for mass flow determination were collected by using the traversing probe build by Scott for the JT8D in the previous EPA program. The traversing probe was modified to include a static pressure probe and a total temperature thermocouple. This new probe was mounted two inches above the emissions sampling probe. The emissions sampling probe was alternately connected to either the emissions

analyzer or to a manometer and thus served as both a total pressure probe and emissions probe. Emissions and aerodynamic measurements were performed on a two-inch square grid. While the gas emissions and total pressure were being measured in one 2 x 2 area, the total temperature and static pressure were being measured in the 2 x 2 area just above.

The "total" temperature indicator was an unshielded chromel-alumel thermocouple attached to the shaft of the static pressure probe and held away from the rounded nose of the static pressure probe approximately one half inch by a spacer. A stream temperature probe is an impractical instrument since it is impossible to measure the temperature exclusive of aerodynamic heating effects.

The temperature of a high speed air stream is most conveniently measured with a total temperature probe which measures the temperature of the stream plus the temperature rise due to adiabatically decelerating the air stream to essentially zero velocity. The stream temperature is then obtained by deducting the aerodynamic heating effect which is a well understood function of Mach number and the ratio of the specific heats.

Total pressure, stream (static) pressure and "total" temperature readings were taken on the two-inch square grid on a plane two inches behind the plane of the exhaust nozzle. The traverse grid is illustrated in Figure 3-1.

3.1.2 Mass Flow Calculations

Mass flow rates were calculated from the pressure and temperature data. The mass flow parameter (ρV) at each grid point was calculated from the static, barometric and total pressure and the total temperature. The Mach number was first calculated using the formula:

$$M = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{P_o}{P_s}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

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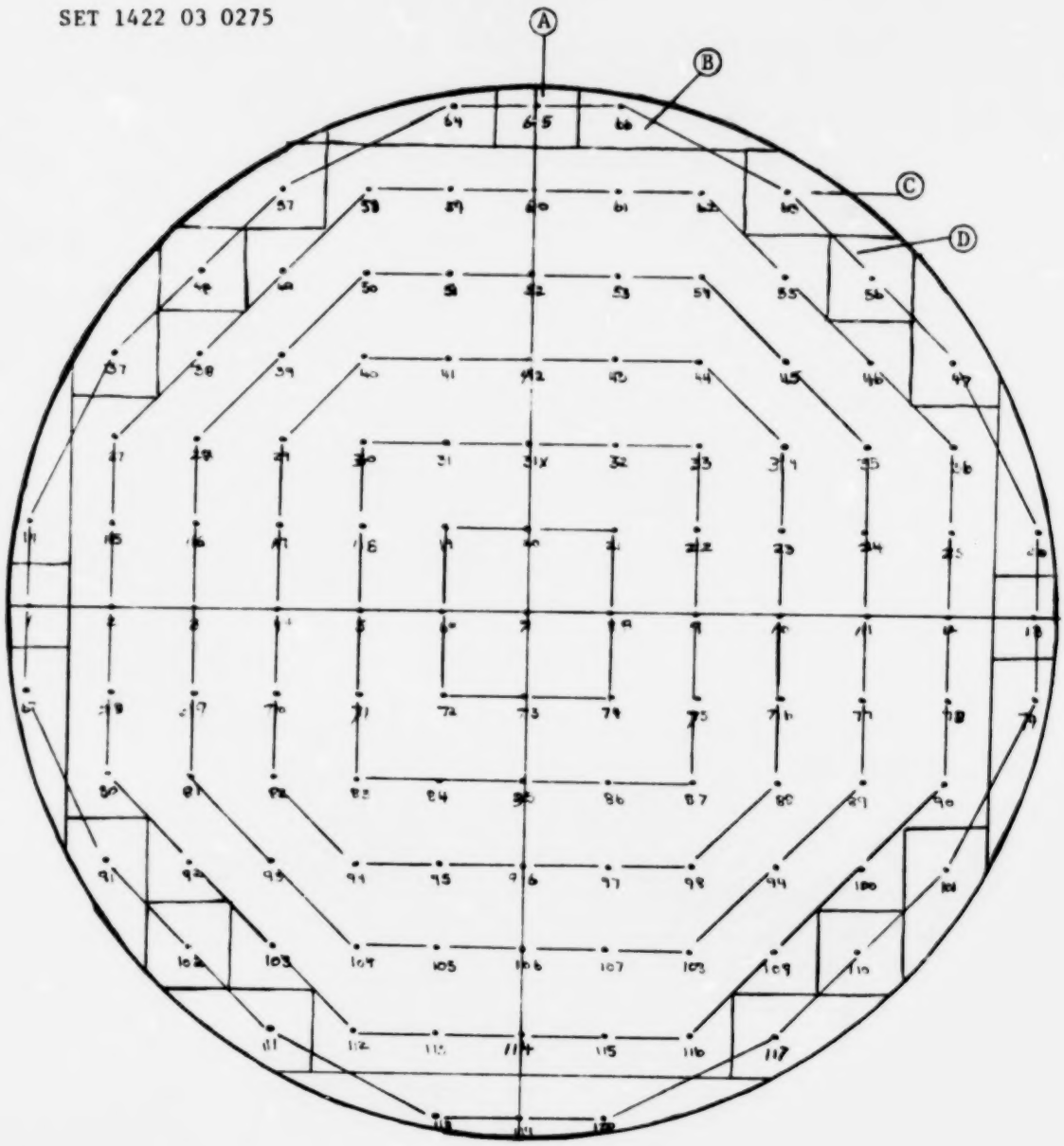

FIGURE 3-1

TRAVERSE GRID

P&W TF 30 ENGINE

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where: M = Mach number

p_o = total pressure #/ft.^{2} (absolute)

p_s = stream pressure #/ft.^{2} (absolute)

γ = ratio of specific heat at constant pressure to the specific heat at constant volume. The value of γ for the exhaust was assumed to be the same as for air (γ = 1.38 for an absolute temperature of 1000° R), γ varies with temperature and fuel-air ratio of the fluid. The stream temperature in the TF30 exhaust varies between 500° R at the nozzle wall at idle and 1300° R in the center at maximum continuous power. Therefore, the value of γ varies from 1.401 to 1.362. The average is 1.38. The error due to using the average value for the calculations is .01% at idle and .12% at maximum continuous power.

The free stream temperature was calculated from the total temperature (T_o) using the relationship:

$$T_s = \frac{T_o}{1 + \frac{M^2}{5}}$$

The speed of sound (V_a) in the exhaust gas is:

$$V_a = \sqrt{\gamma g\ RT_s}$$

where: g = the dimensional constant 32.17 ft./sec.^{2} and R for air is 53.3.

The exhaust velocity (V) at each point is:

$$V = M(V_a)$$

The exhaust gas density at each point is:

$$\rho = \frac{P_s}{g\ RT_s} \quad \frac{(\text{slugs})}{\text{ft.}^3}$$

The mass flow per unit area (ρV) at each point was obtained from the product of ρ and V and is in the units slugs/ft.^{2} - sec.

3.1.3 The Effect of Pressure and Temperature Measurement Errors on Mass Flow Data

The static pressure probe was made of one-half inch diameter tubing bent in an inverted L shape with the small leg of the inverted L projecting into the exhaust stream. Static pressure taps were located one inch back from a rounded nose added to the tube. The position of the static pressure tap on the body of the static pressure probe should be located far enough aft of the nose of the probe to be free of the flow disturbance produced by the nose and far enough forward of the stem so that the presence of the stem which is propagated upstream is minimal.(3) In the probe used the static pressure port was located 2 probe diameters downstream of the nose and sufficiently forward of the stem to minimize flow disturbance. The stem error in the static pressure is minimal because the sample port is located far upstream of the stem. The static pressure error produced by the nose of the probe can be as high at 1.5% of the stagnation pressure or about 1.6 inches of water at idle power. Since the calculations for velocity and density require the static pressure in absolute units this error is seen to be negligible.

The errors in the total temperature measurement are caused by radiation and conduction losses from the thermocouple junction and uncertainties in the actual degree of stagnation pressure recovery. The ability of the total temperature probe to decelerate the fluid to zero and convert the kinetic energy of the fluid to thermal energy is characterized by its recovery factor. The recovery factor is 1.0 for a perfect probe. For a bare bulb thermocouple, similar to that used in the tests, the recovery factor can be no better than .65 when radiation and conduction is minimized.(3) The radiation is minimized when the probe temperature is close to the wall temperature. For purposes of estimating the error involved in using a bare thermocouple in a jet exhaust, let us assume that the radiation and conduction error is either small or self-cancelling and that the only error is due to deviation of the probe temperature from the stream stagnation temperature. The ratio of the total temperature to the stream temperature may be estimated from

$$\frac{T_t}{T_s} = 1 + \frac{M^2}{5}$$

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3.2 EXHAUST MASS FLOW PATTERNS

3.2.1 Temperature and Pressure Patterns

Detailed patterns of exhaust gas temperature taken on the TF30 are presented in Figures 3-2, 3-3, and 3-4 for idle, approach and maximum continuous power. A map of total pressure for idle is shown in Figure 3-5. The total pressure pattern becomes flatter with increasing power, being essentially flat at maximum continuous power. Total temperature and static pressure data at idle were missing at 16 of the outer grid points and idle power total temperature data were missing at 7 additional grid points. Using the grid pattern of Figure 3-1, the average value of temperature for each ring of grid points was calculated and this value was used as an estimate of the temperature at the missing points. Missing data at approach power and maximum continuous power were treated similarly. The temperature patterns are smooth and symmetrical. The overall exhaust gas temperature level increased less than 10% with increasing power and the temperature gradient decreased with increasing power.

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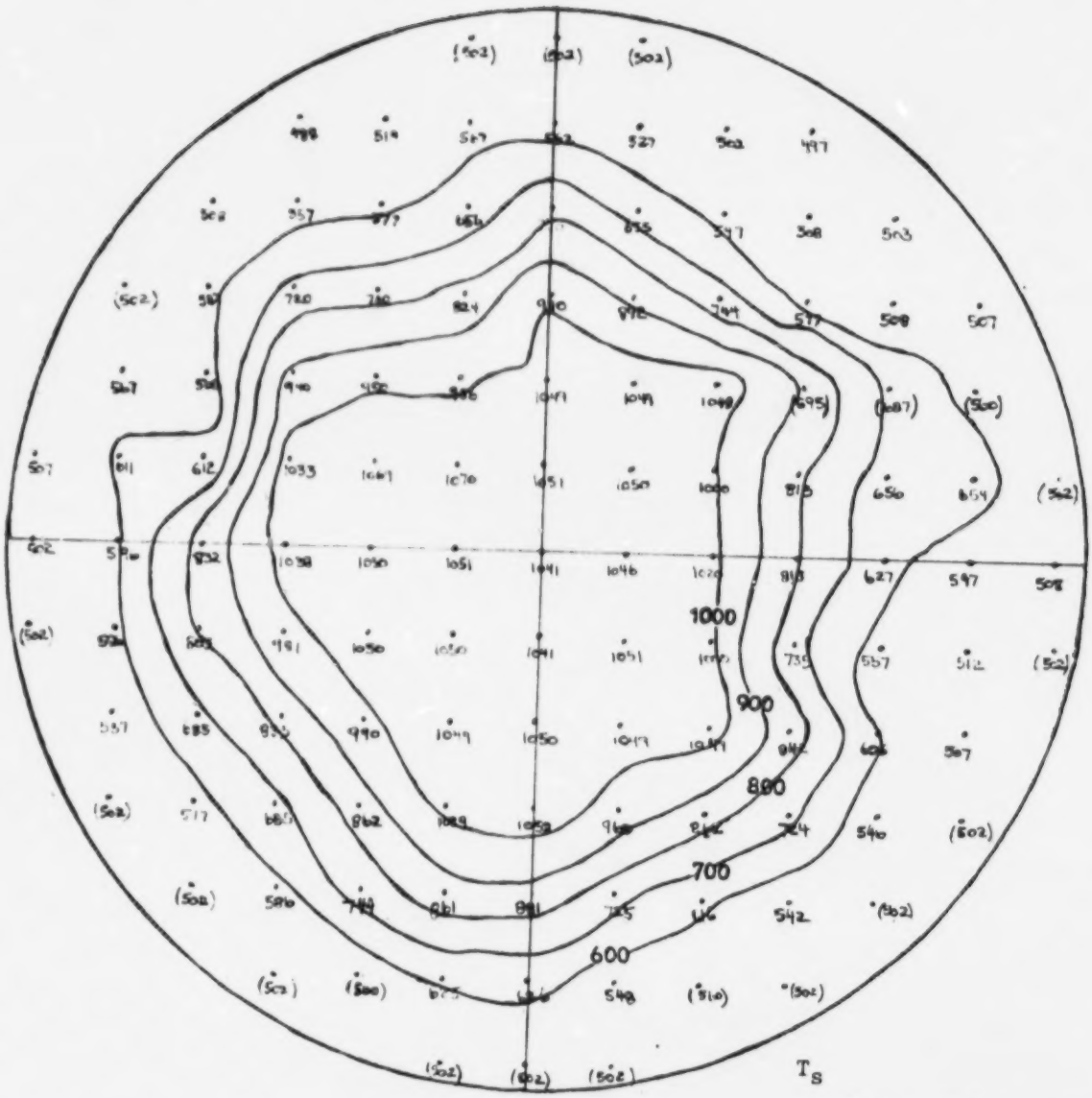

FIGURE 3-2

EXHAUST GAS STATIC TEMPERATURE MAP (^{o}R)

P&W TF 30 ENGINE IDLE POWER

LOOKING UPSTREAM

Note: Values shown in parentheses are assumed values based on symmetry.

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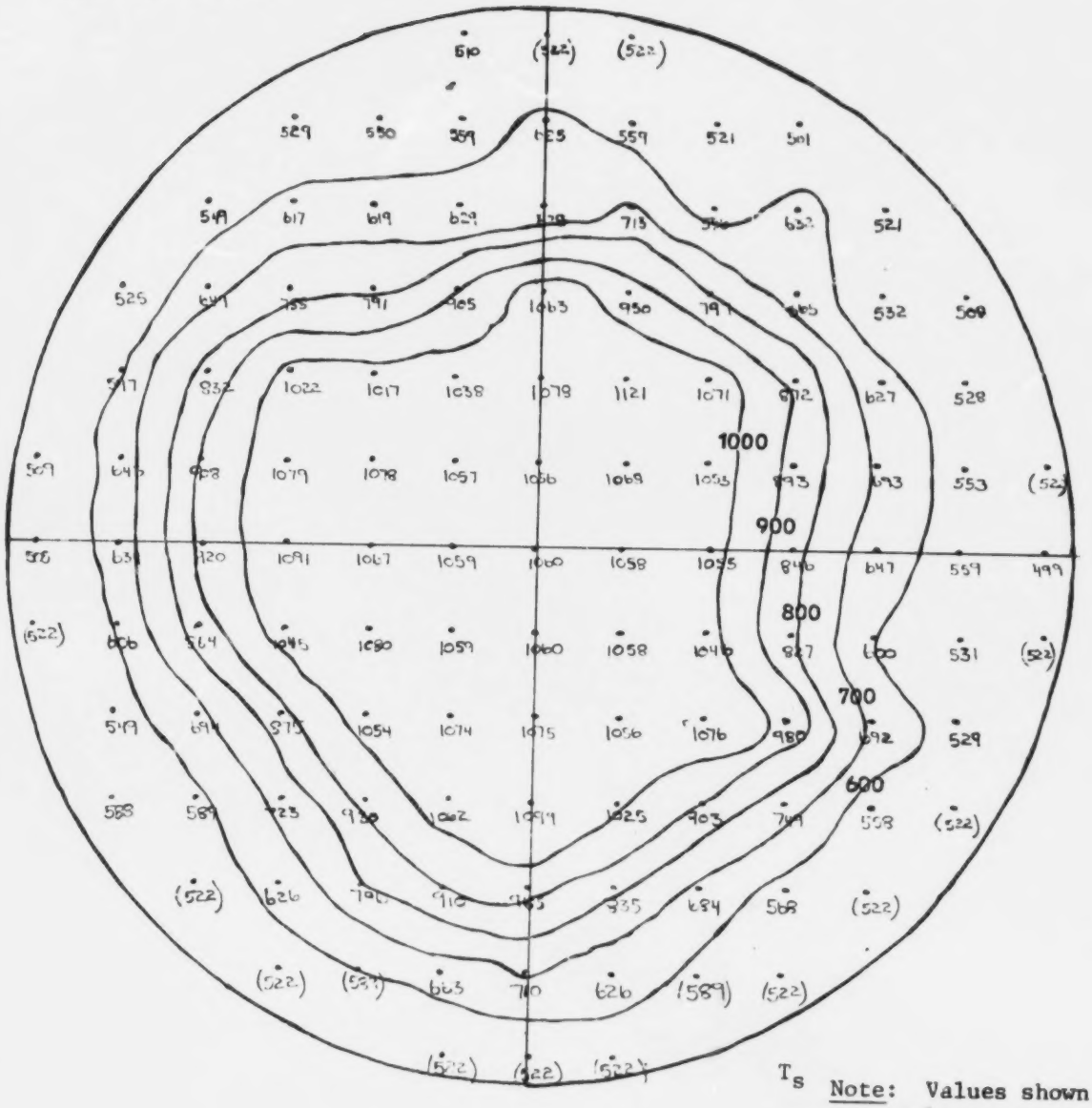

T_s

Note: Values shown in parentheses are assumed values based on symmetry.

FIGURE 3-3

EXHAUST GAS STATIC TEMPERATURE MAP (^{o}R)

P&W TF 30 ENGINE APPROACH POWER

LOOKING UPSTREAM

SET 1422 03 0275

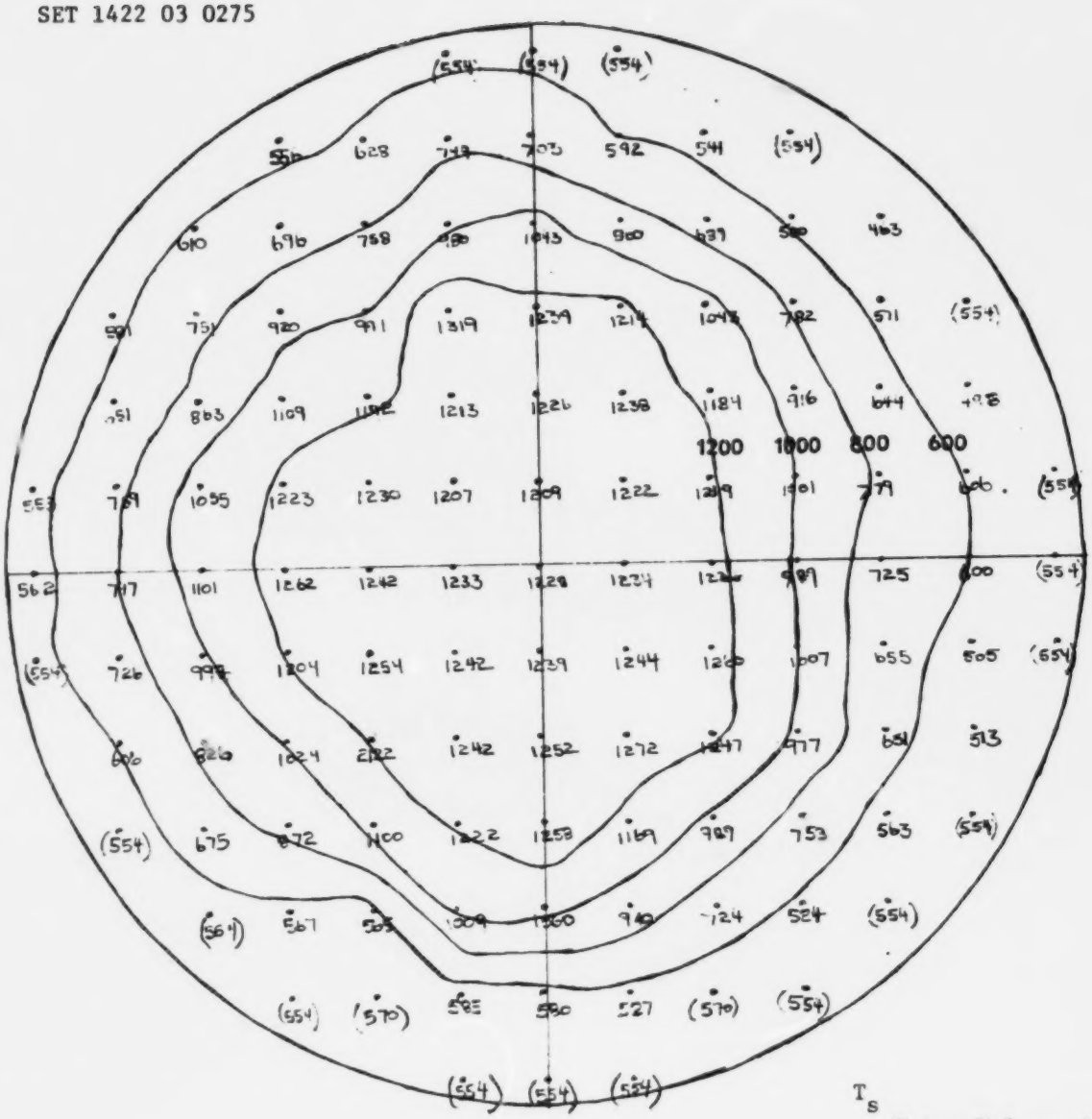

FIGURE 3-4

EXHAUST GAS STATIC TEMPERATURE MAP ($^{\circ}$R)

P&W TF 30 ENGINE MAXIMUM CONTINUOUS POWER

LOOKING UPSTREAM

Note: Values shown in parenthesis are assumed values based on symmetry.

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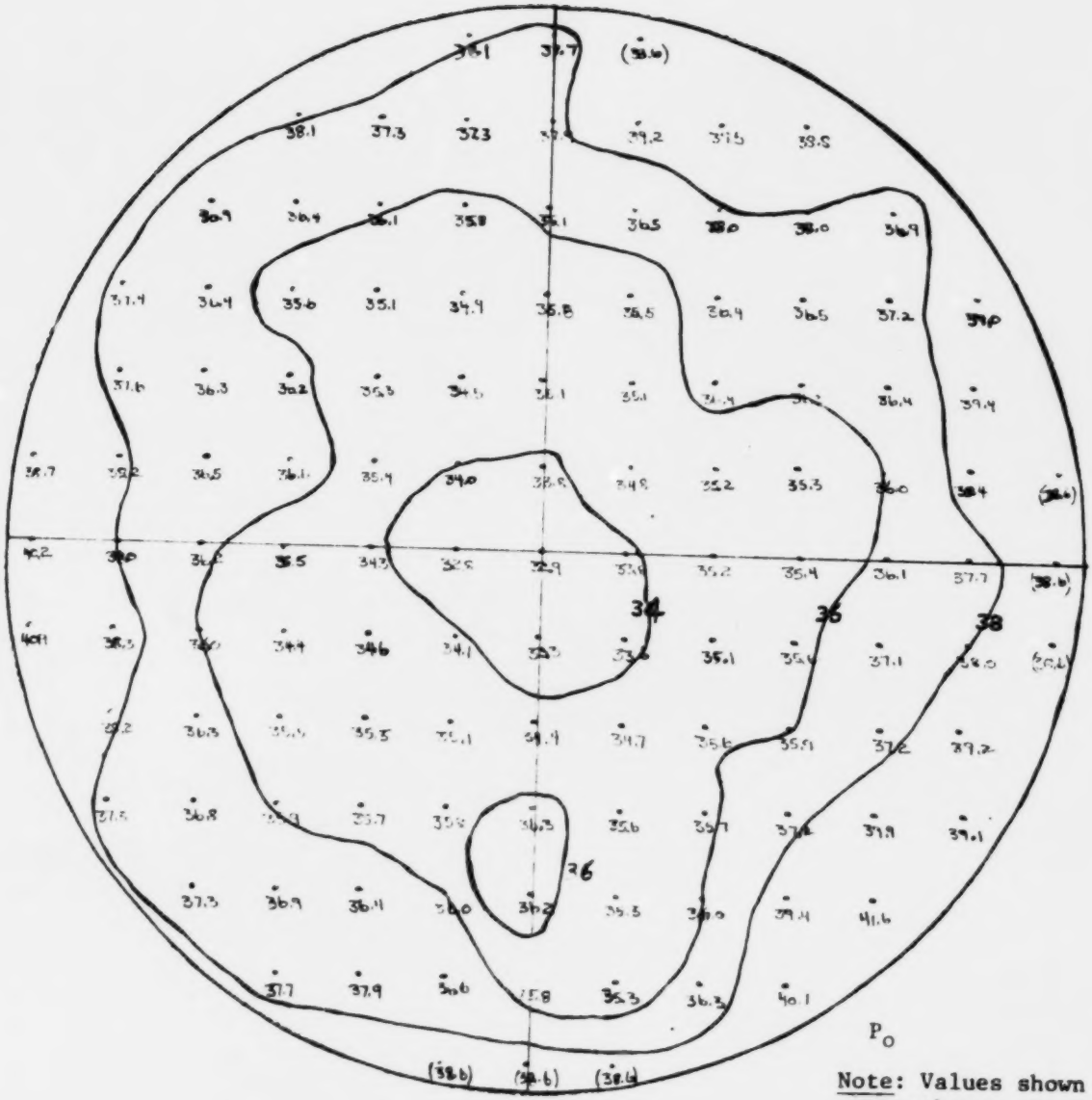

Note: Values shown in parentheses are assumed values based on symmetry.

FIGURE 3-5

TOTAL PRESSURE MAP (inches H_2O gage)

P&W TF 30 ENGINE IDLE POWER

LOOKING UPSTREAM

SET 1422 03 0275

3.2.2 Density, Velocity and Mass Flow Profiles

Typical profiles of the density (ρ) and velocity (V) are shown as Figures 3-6, 3-7 and 3-8 for idle, approach and maximum continuous power. The profiles were obtained by plotting the calculated velocity and density from the data points in the horizontal center line of the exhaust plane. Exhaust gas velocity is seen to be highest near the center with a small depression at the center and decreasing toward the edge of the nozzle at all power settings. The central velocity is approximately 25% greater than the velocity near the periphery. The density profile is fairly flat in the center and increases in density toward the nozzle periphery at all power settings. The density approximately doubles from the center to the edge.

The density and velocity at each grid point were combined into a mass flow parameter ρV. This parameter has the units mass per area per unit time. The data are tabulated in Appendix I. Where data were missing, estimated ρV values were determined by averaging data for other points in the same concentric ring. These estimated points are identified by enclosing them in parentheses.

Figures 3-9, 3-10 and 3-11 illustrate the mass flow distribution at the TF-30 exhaust nozzle at idle, approach and maximum continuous power. At idle power, the mass flow varies smoothly from 0.5 slugs/ft.^{2}-sec. (78.5 kg/m^2-sec.) in the center of the exhaust to 0.9 slugs/ft.^{2}-sec. (141 kg/m^2-sec.) at the nozzle wall. At approach and maximum continuous power, the mass flow distribution becomes a little flatter but is still highest at the outer wall and lowest in the center. The approximate ratios of wall to center mass flow rates are 1.67, 1.54 and 1.49 for idle, approach and maximum continuous power. Based on these mass flow distributions, it would be expected that the exhaust aerodynamic effects would be similar on a multiple point sampling probe at all power settings.

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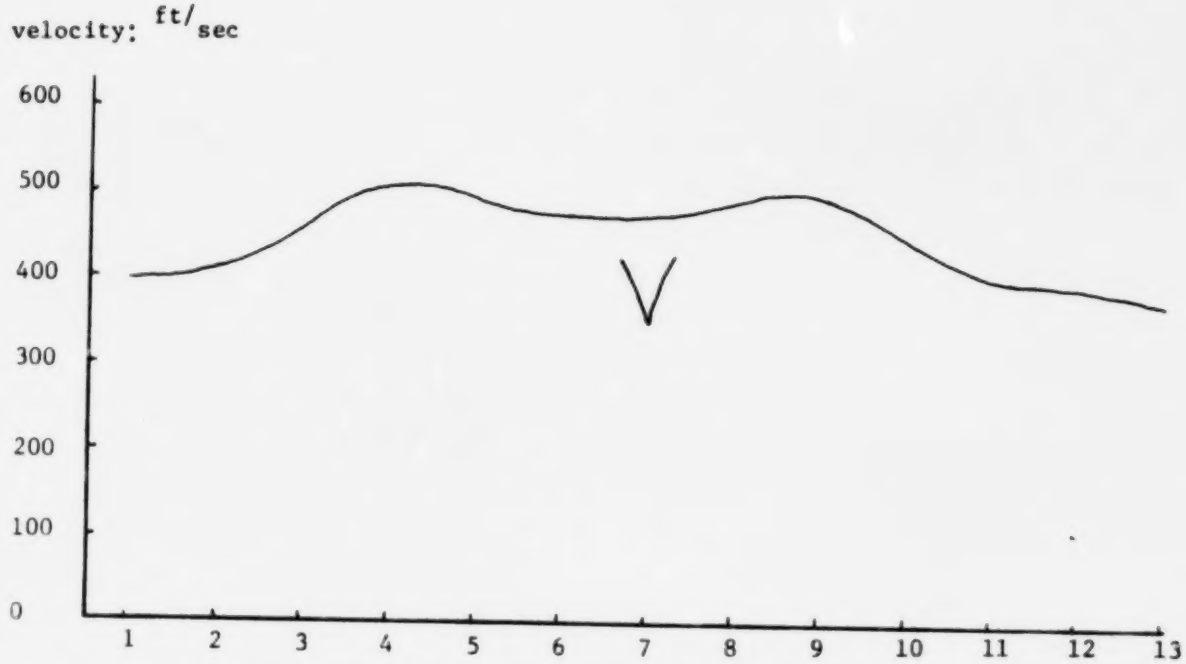


TYPICAL VELOCITY AND DENSITY PROFILES

TF 30 ENGINE IDLE POWER

Rdg. No. 14

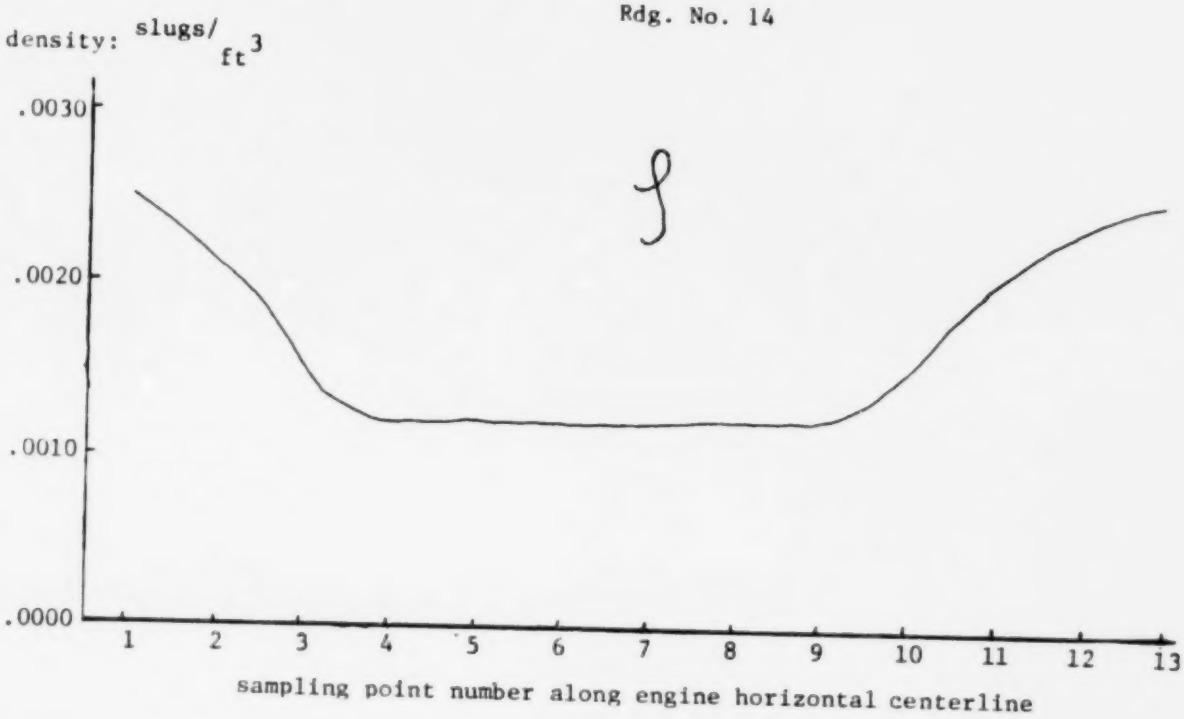
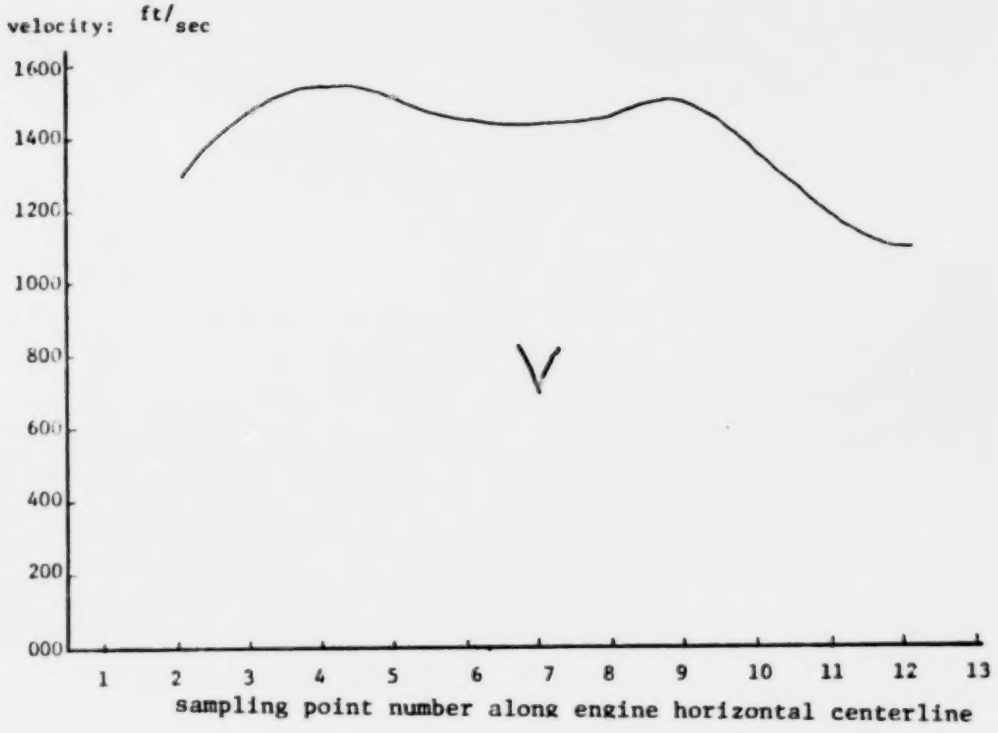


Figure 3-6

SET 1422 03 0275



TYPICAL VELOCITY AND DENSITY PROFILES
TF 30 ENGINE MAXIMUM CONTINUOUS POWER
Rdg. No. 17

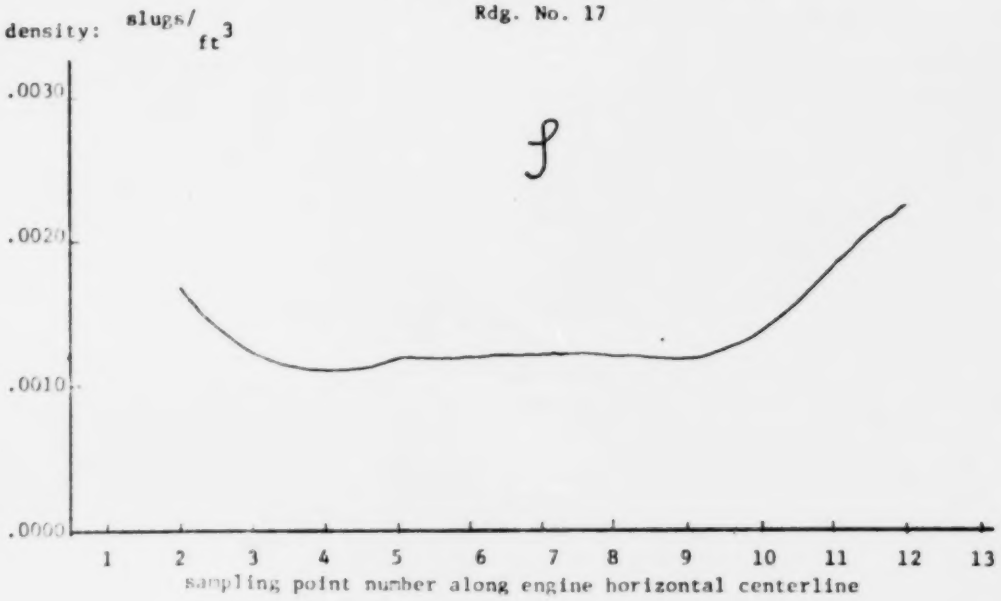
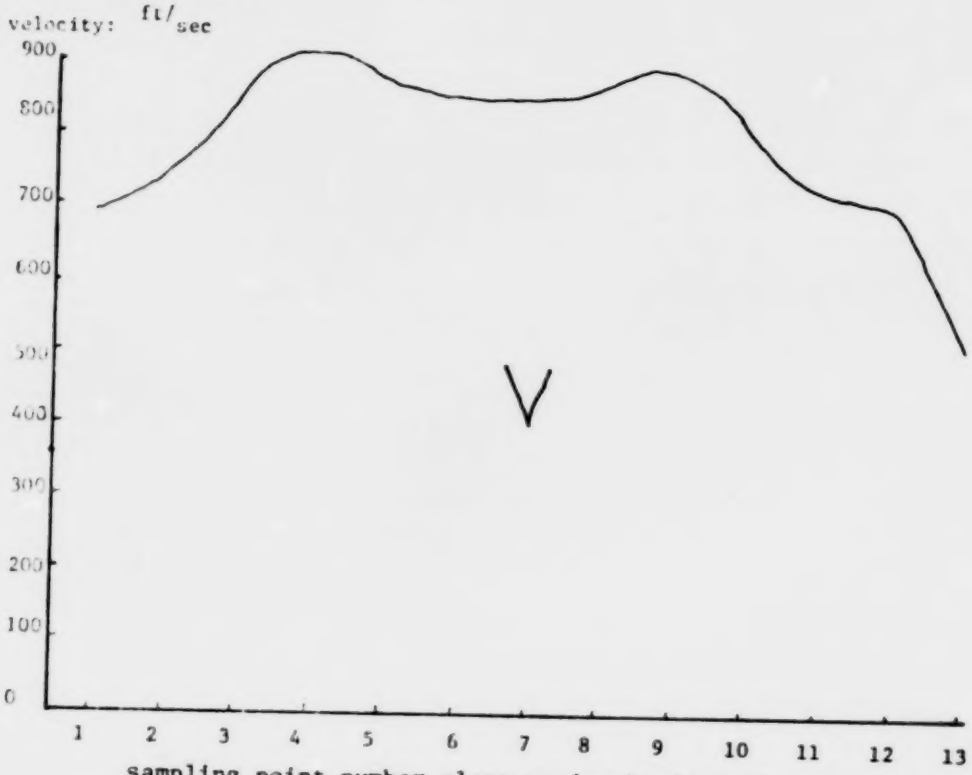


Figure 3-7

SET 1422 03 0275



TYPICAL VELOCITY AND DENSITY PROFILES

TF 30 ENGINE APPROACH POWER

Rdg. No. 15

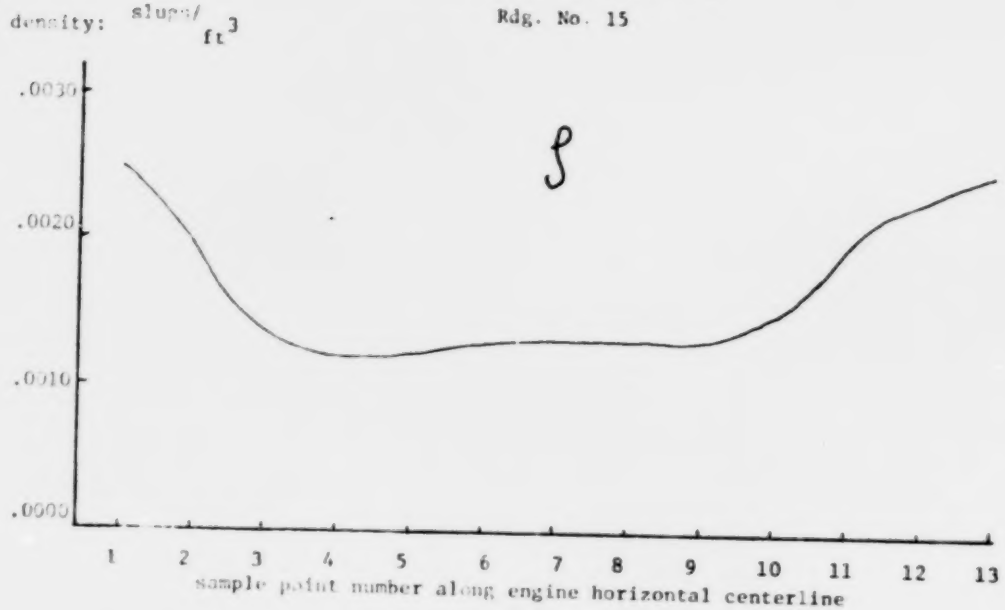


Figure 3-8

SET 1422 03 0275

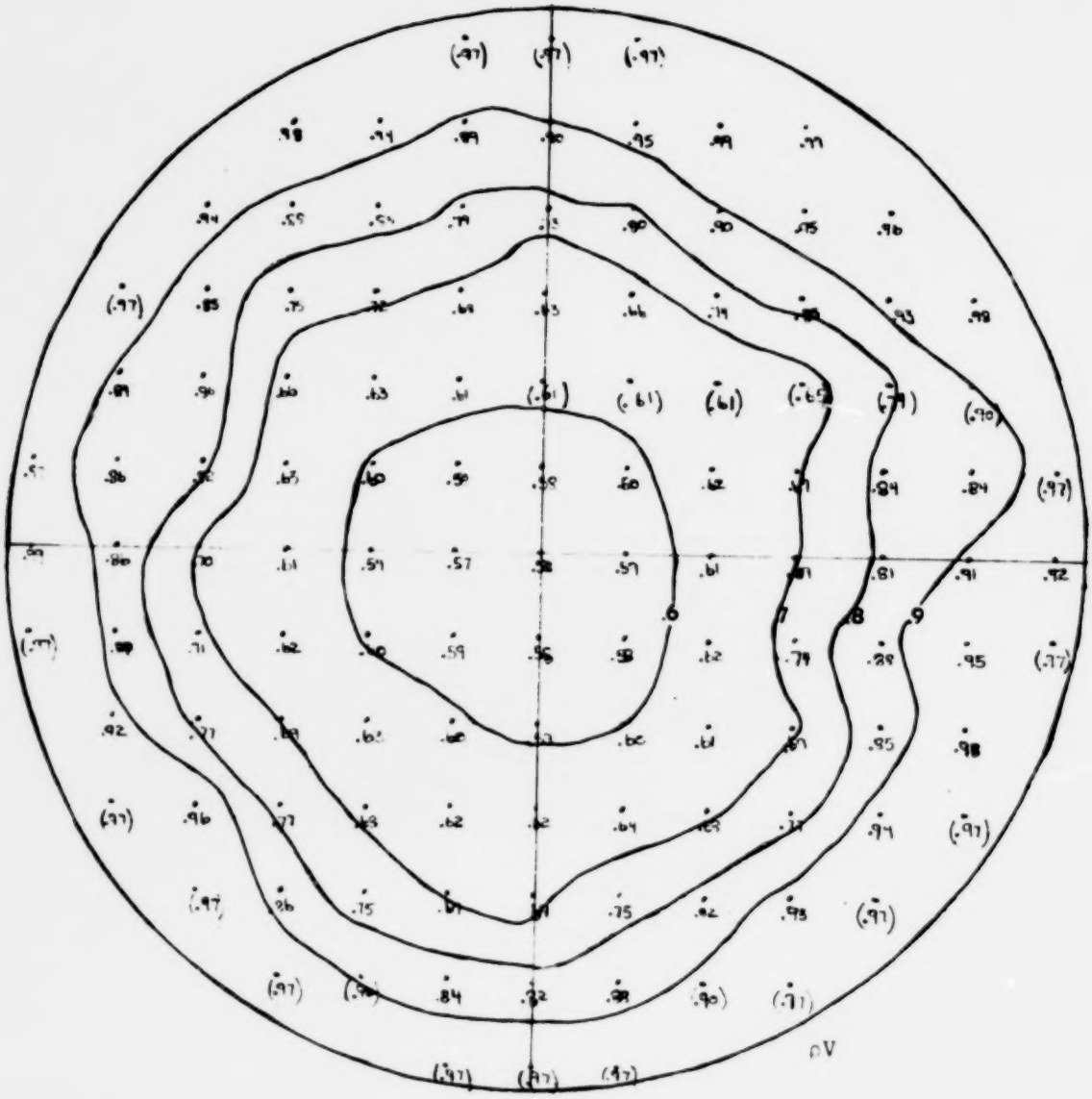


FIGURE 3-9

MASS FLOW DISTRIBUTION ($\frac{\text{slugs}}{\text{ft}^2 \text{ sec}}$)

P&W TF 30 ENGINE IDLE POWER

LOOKING UPSTREAM

SET 1422 03 0275

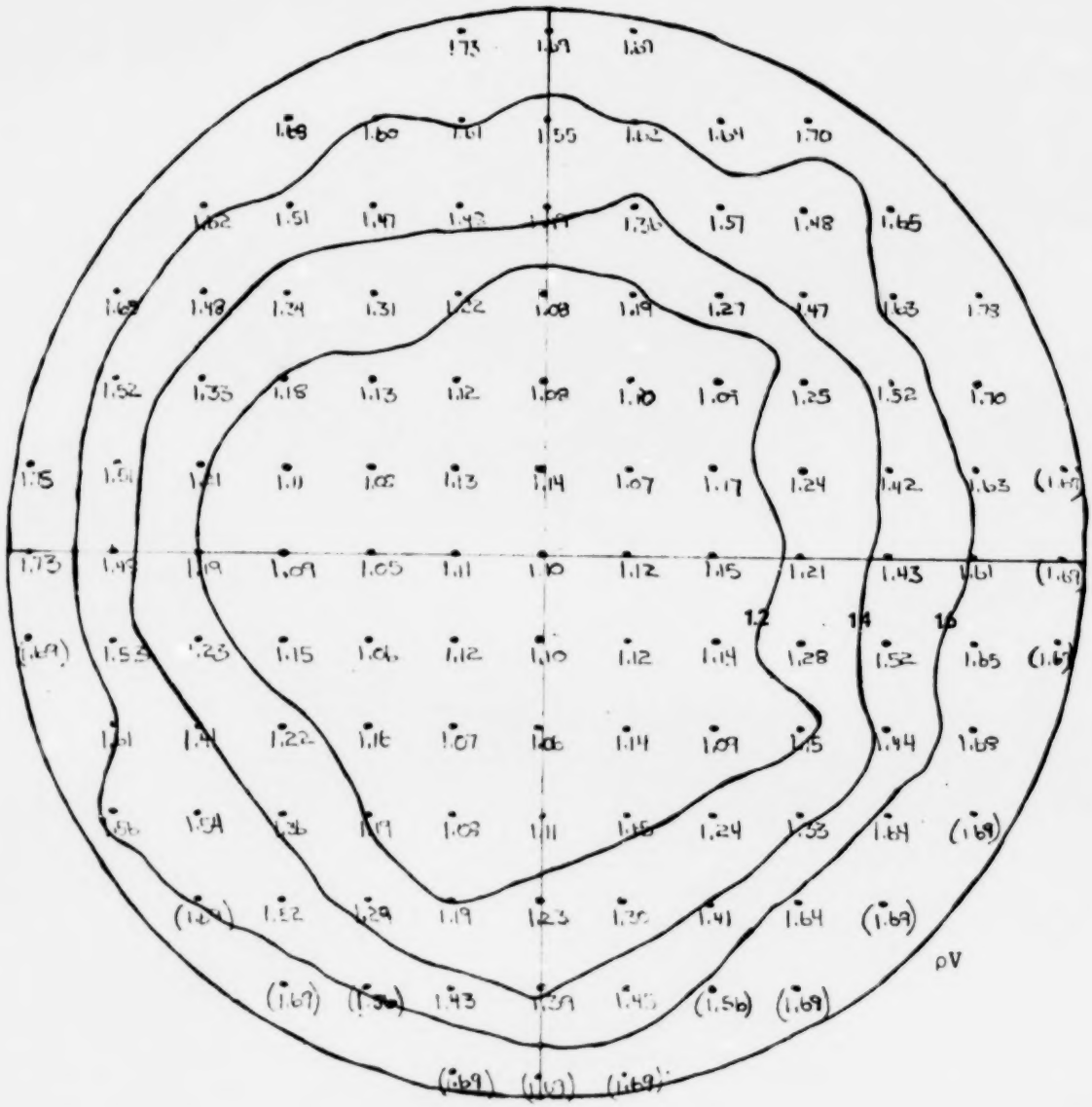


FIGURE 3-10

MASS FLOW DISTRIBUTION ($\frac{\text{slugs}}{\text{ft}^2 \text{ sec}}$)

P&W TF 30 ENGINE APPROACH POWER

LOOKING UPSTREAM

SET 1422 03 0275

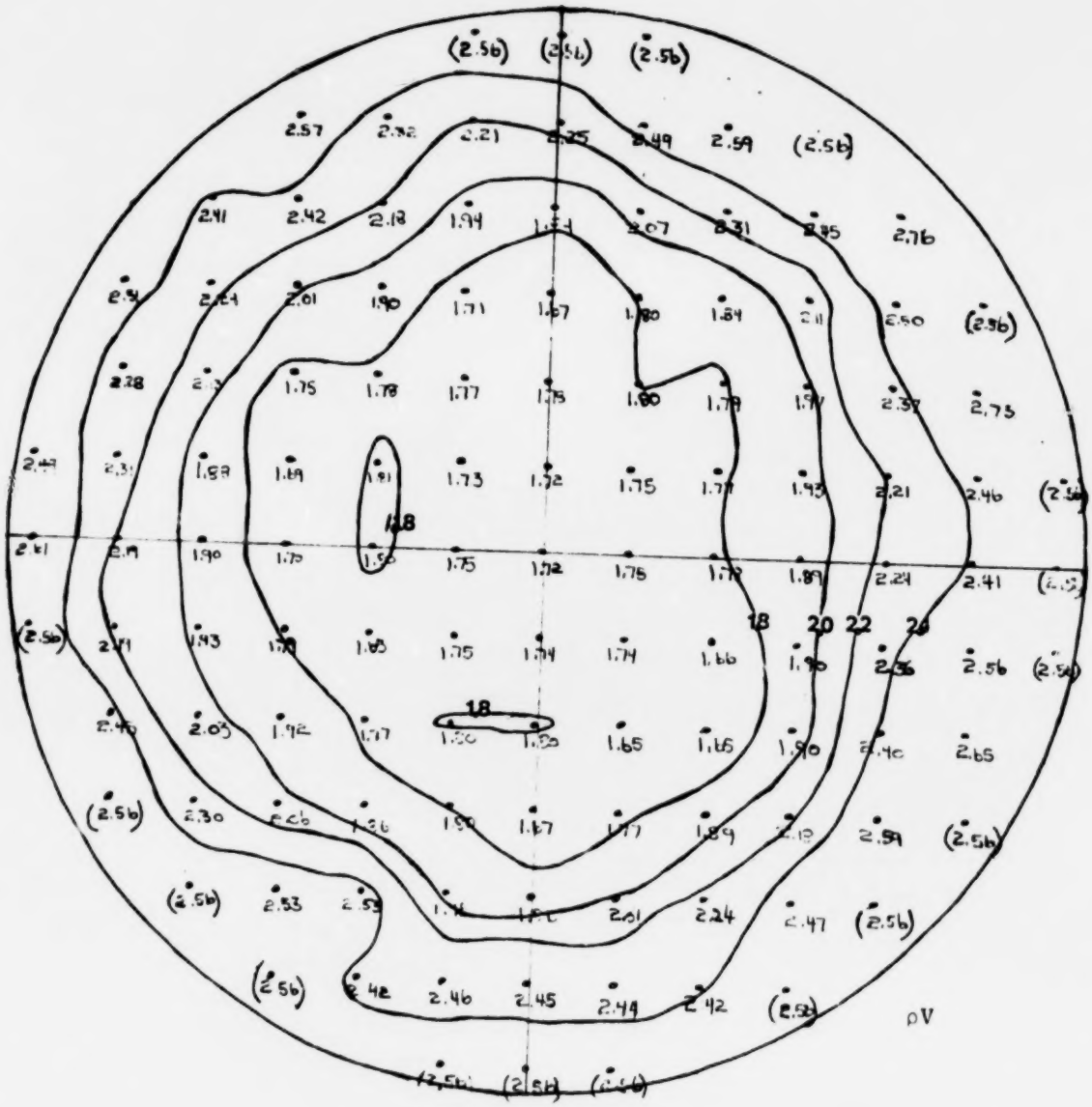


FIGURE 3-11
MASS FLOW DISTRIBUTION ($\frac{\text{slugs}}{\text{ft}^2\ \text{sec}}$)
P&W TF 30 ENGINE MAXIMUM CONTINUOUS POWER
LOOKING UPSTREAM

SET 1422 03 0275

3.2.3 Calculation of Total Exhaust Mass Flow

The average mass flow, ($\overline{\rho V}$), at each power setting was calculated and multiplied by the nozzle cross sectional area to yield the exhaust flow rate in pounds per second. These values were compared to the exhaust flow rate obtained from the bellmouth air flow and fuel flow measurements made during the same traverse runs. These data are shown in Table 3-1.

TABLE 3-1 COMPARISON OF CALCULATED TOTAL EXHAUST FLOW

NAFEC Rdg. No.	Power Setting	Bellmouth Air Flow #/Sec.	Fuel Flow #/Hr.	Exhaust Flow(1) #/Sec.	Exhaust Flow(2) #/Sec.	% Diff.
14	Idle	76.2	871	76.4	86.6	13.2
15	Approach	141.0	2230	144.6	152.4	5.4
17	Max.Cont.Power	218.3	5249	219.8	238.0	8.0

(1) Based on air plus fuel flows.

(2) Calculated from $\overline{\rho V}$.

The flow rates calculated from the mass flow measurements are from 5 to 13% higher than the sum of the measured air and fuel flow rates. The error in total temperature measurement during traverse will cause the calculated $\overline{\rho V}$ values to be in error by a factor inversely proportional to the square root of the error. Since the total temperature could have been too low by 2 to 16%, the $\overline{\rho V}$ flow calculation could be from 1% high at idle to 4% high at maximum continuous power. The differences in the flow rates determined by the two methods are considerably greater, especially at idle. The possible instrumental error sources are the bellmouth flow orifice calibration and unknown systematic errors in the temperature and pressure measurements. The primary source of error cannot be determined from available data.

SET 1422 03 0275

3.3 EXHAUST POLLUTANT EMISSION RATES

3.3.1 Pollutant Emission Concentration Maps

Detailed exhaust gas concentration measurements were made concurrent with the mass flow traverse measurements at the TF30 exhaust plane. The exhaust emission measurements were made with a new analysis system built to conform with the EPA Aircraft Test Procedures CFR 40 of Part 87 July, 1973. The point by point data are presented in Appendix I.

Exhaust concentration maps for carbon dioxide, carbon monoxide and total hydrocarbons at idle power setting are presented in Figures 3-12 through 3-14. Similar maps at approach power are shown in Figures 3-15 through 3-17. Maps for carbon dioxide and nitrogen oxides at maximum continuous power are given in Figures 3-18 and 3-19. The maps for nitrogen oxides at idle and approach and those for carbon monoxide and total hydrocarbons at maximum continuous power were not drawn because there were too many missing data points.

The maps exhibit smooth, symmetrical pollutant concentration patterns with nearly circular concentric concentration isopleths. The patterns shown in these maps are in sharp contrast with those obtained for the JT8D engine in Scott's previous work for EPA [1]. The JT8D engine exhibited a four-lobed pattern for all exhaust constituents.

3.3.2 Area Weighted vs. Mass Weighted Emission Indices

Area weighted and mass weighted averages of the pollutants at each grid point were calculated from the TF30 engine data given in Appendix I. The reading numbers are 14, 15, 16 and 17. The area weighted averages were calculated by assigning one unit area to each grid point except for the grid points at the outer periphery. Grid points located in the areas labeled A, B, C and D of Figure 3-1 were weighted by areas of .74, 1.18, 1.18 and .98, respectively. Symmetrically located areas on the periphery were weighted with the appropriate factor. The difference between the area weighted average and the numerical average of the data points is less than 1%. This shows that when calculating area weighted average concentrations, where the number of data points is 100 or more, the numerical average of the points is equivalent to the area weighted average. The resulting area weighted averages are given in Table 3-2.

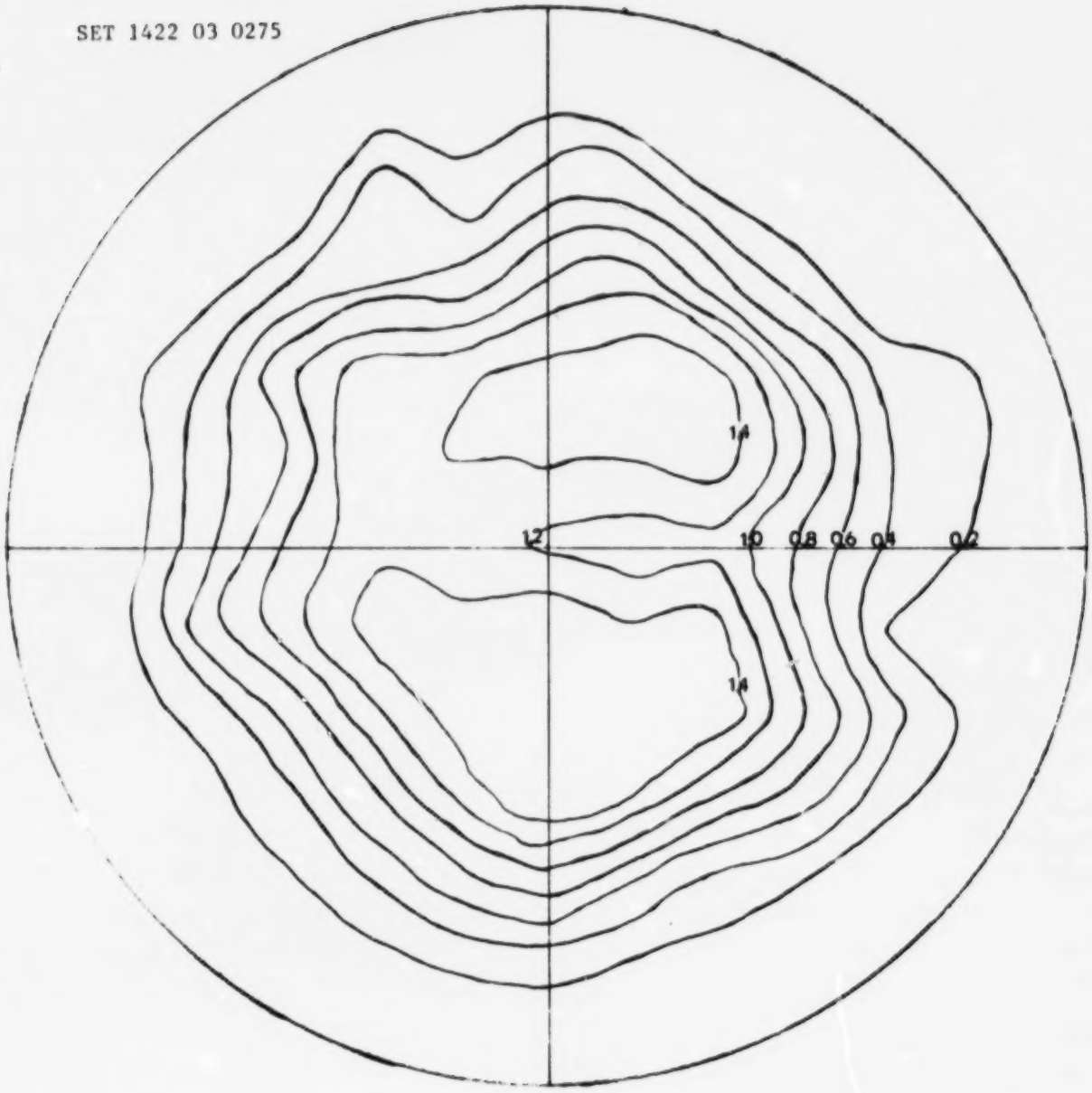


FIGURE 3-12

CO_2 (%)

EXHAUST CONCENTRATION MAP

TF 30 ENGINE IDLE POWER

source: NAFEC

Rdg. No. 14

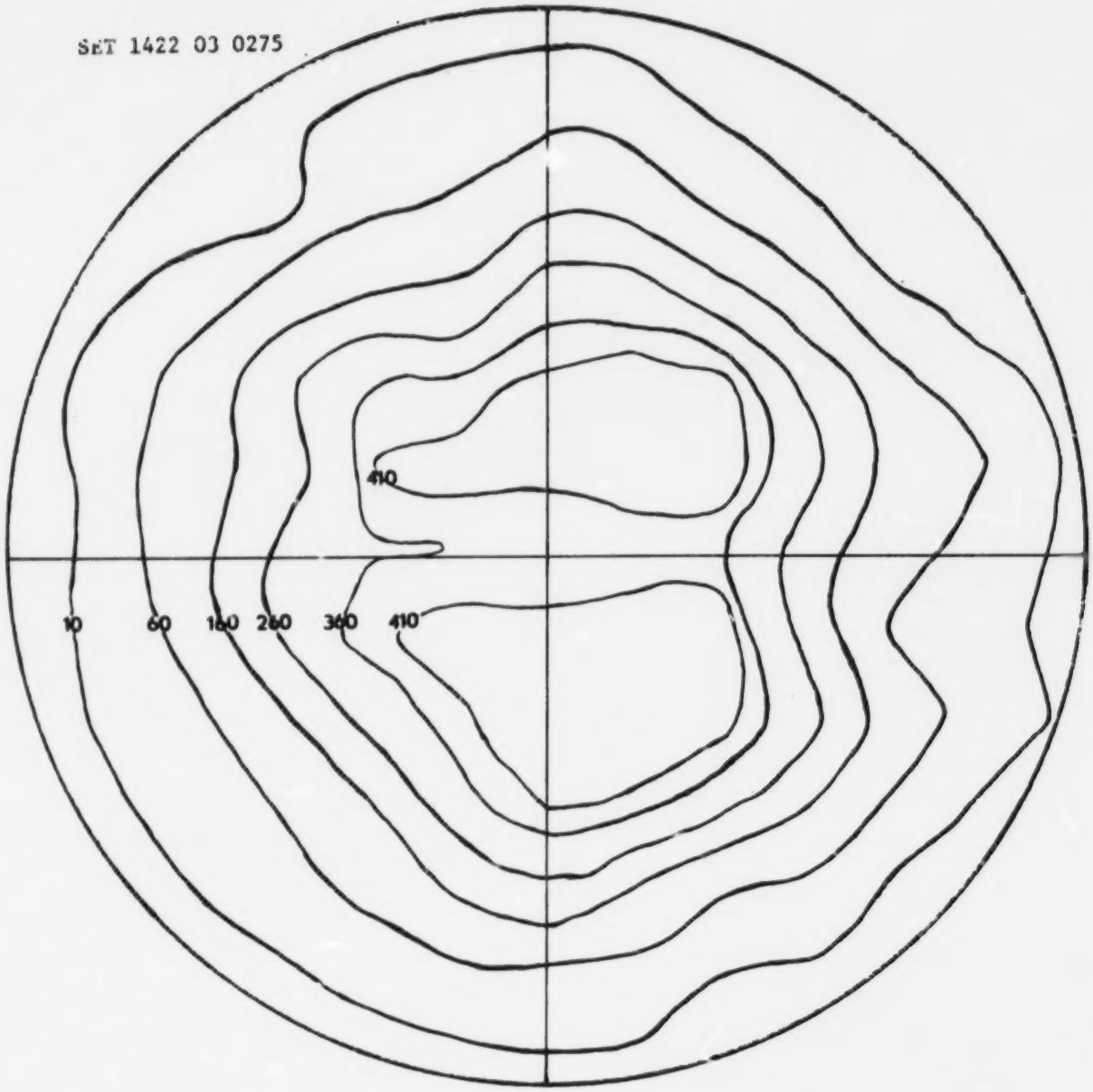


FIGURE 3-13

CO (ppm)

EXHAUST CONCENTRATION MAP

TF 30 ENGINE IDLE POWER

source: NAFEC

Rdg. No. 14

FIGURE 3-14

THC (ppmC)

EXHAUST CONCENTRATION MAP

TF 30 ENGINE IDLE POWER

source: NAFEC

Rdg. No. 14

SET 1422 03 0275

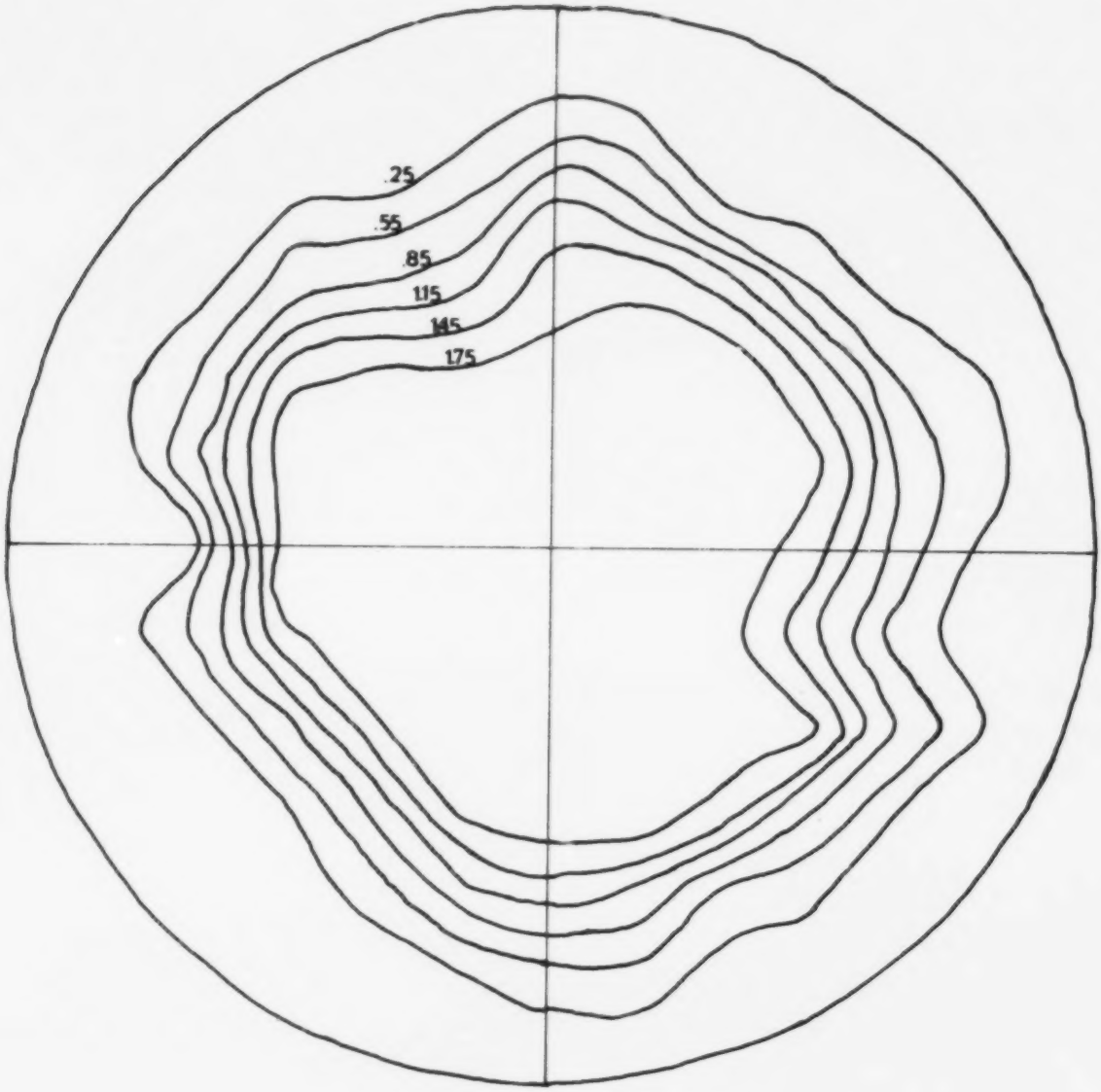


FIGURE 3-15

CO_2 %

EXHAUST CONCENTRATION MAP

TF 30 ENGINE APPROACH POWER

source: NAFEC

Rdg. No. 15

SET 1422 03 0275

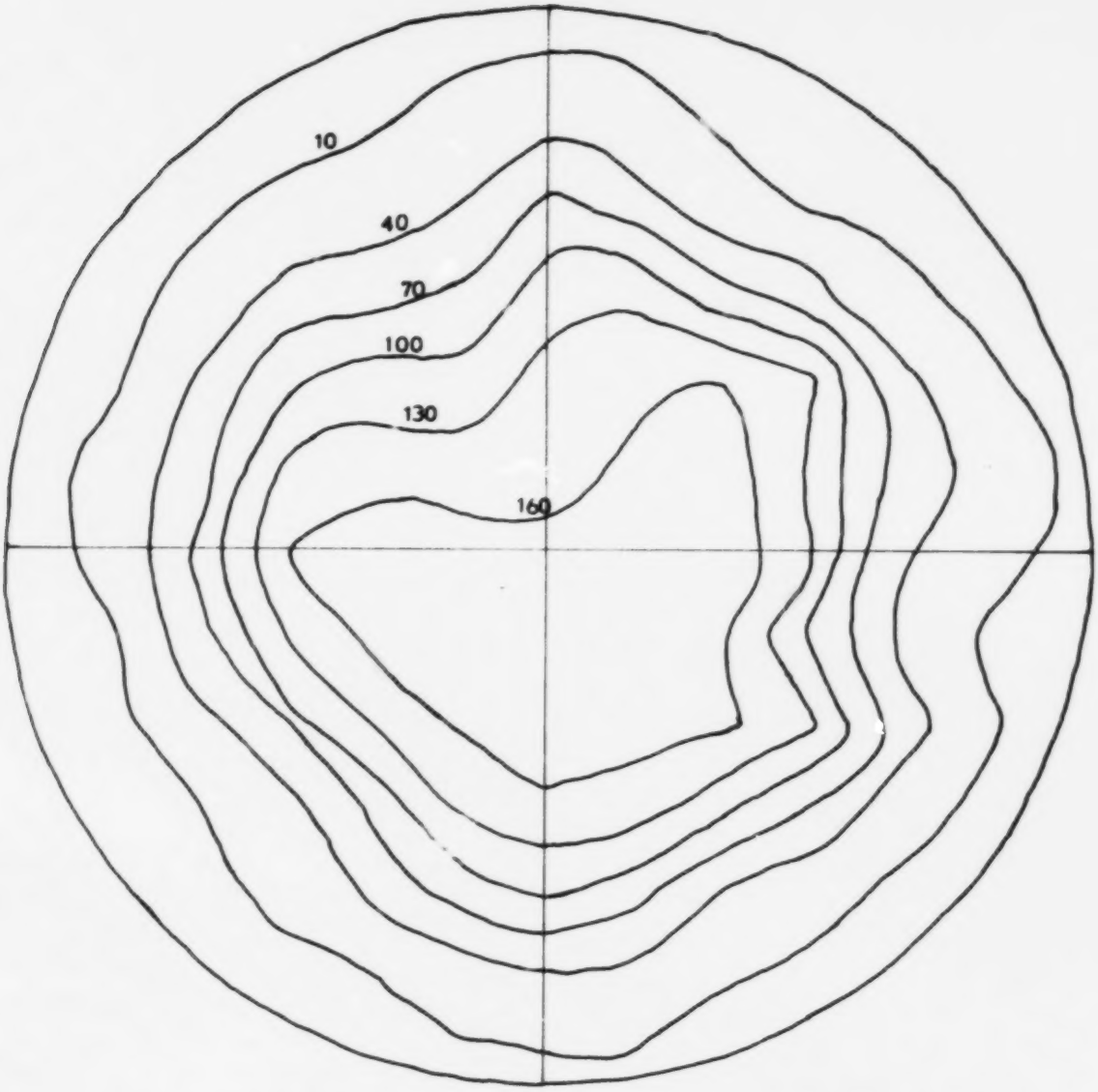


FIGURE 3-16

CO (ppm)

EXHAUST CONCENTRATION MAP

TF 30 ENGINE APPROACH POWER

source: NAFEC

Rdg. No. 15

SET 1422 03 0275

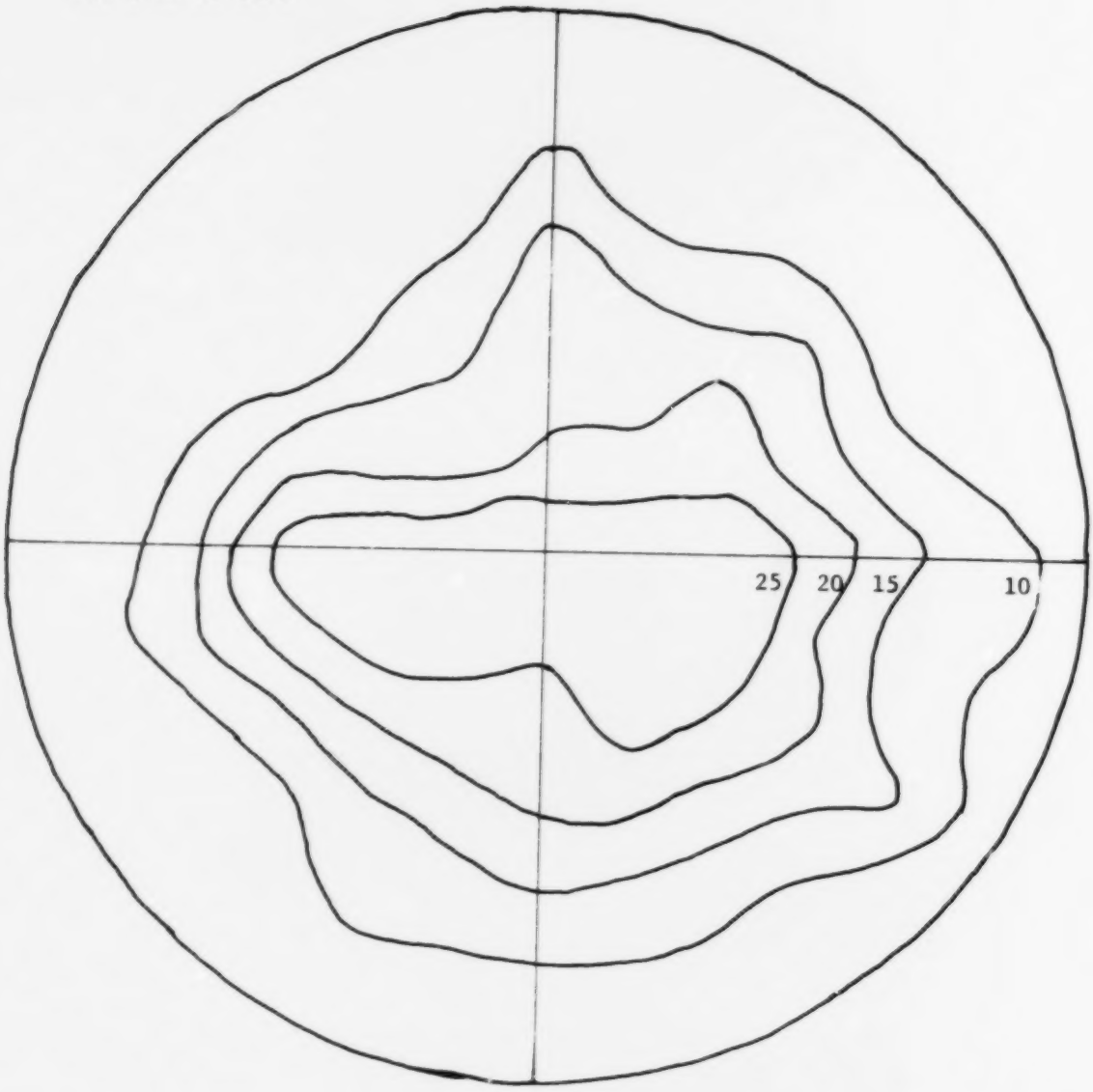


FIGURE 3-17

THC (ppmC)

EXHAUST CONCENTRATION MAP

TF 30 ENGINE APPROACH POWER

source: NAFEC

Rdg. No. 15

SET 1422 03 0275

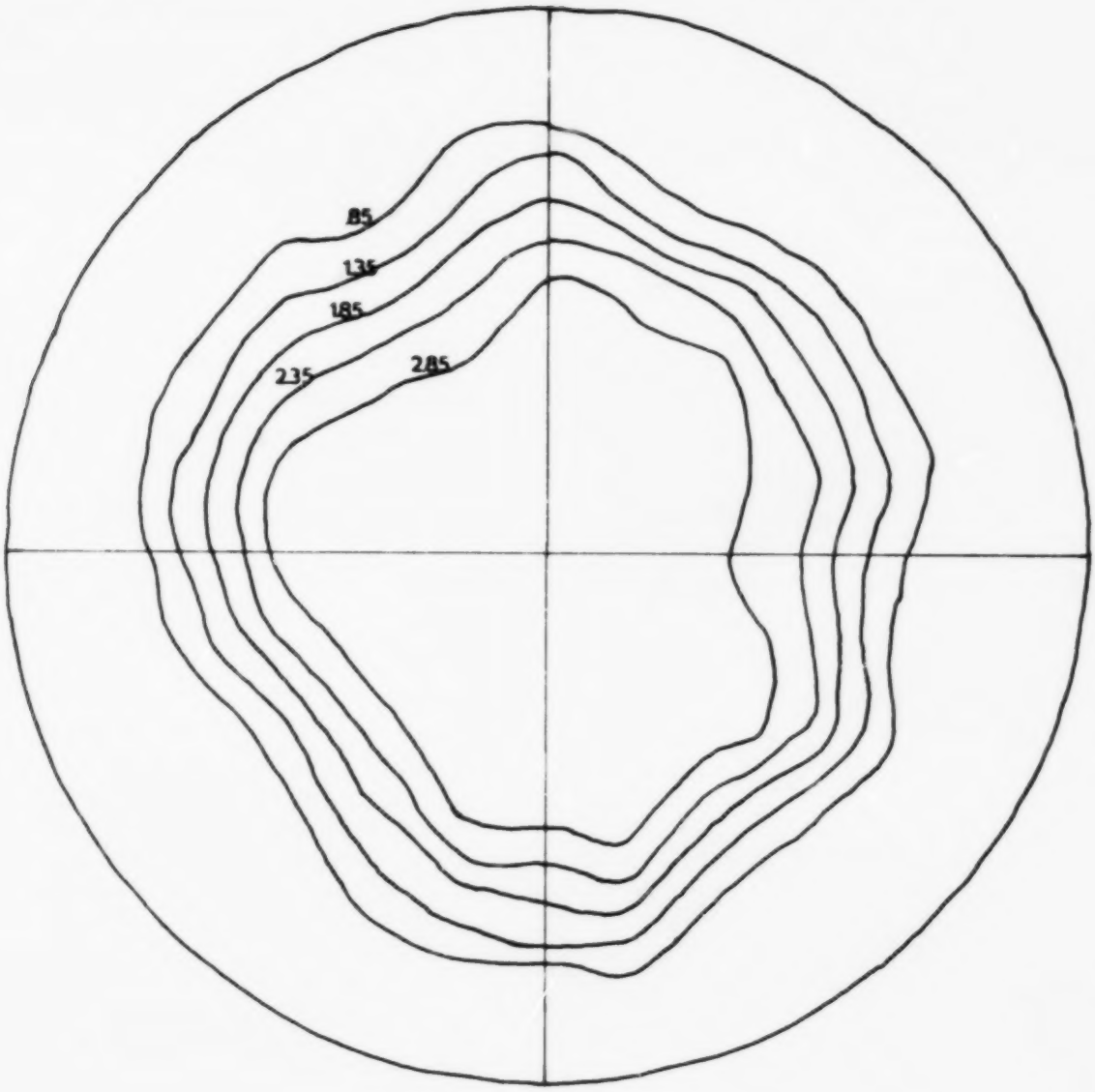


FIGURE 3-18

CO_2 %

EXHAUST CONCENTRATION MAP

TF 30 ENGINE MAXIMUM CONTINUOUS POWER

source: NAFEC

Rdg. No. 17

SET 1422 03 0275

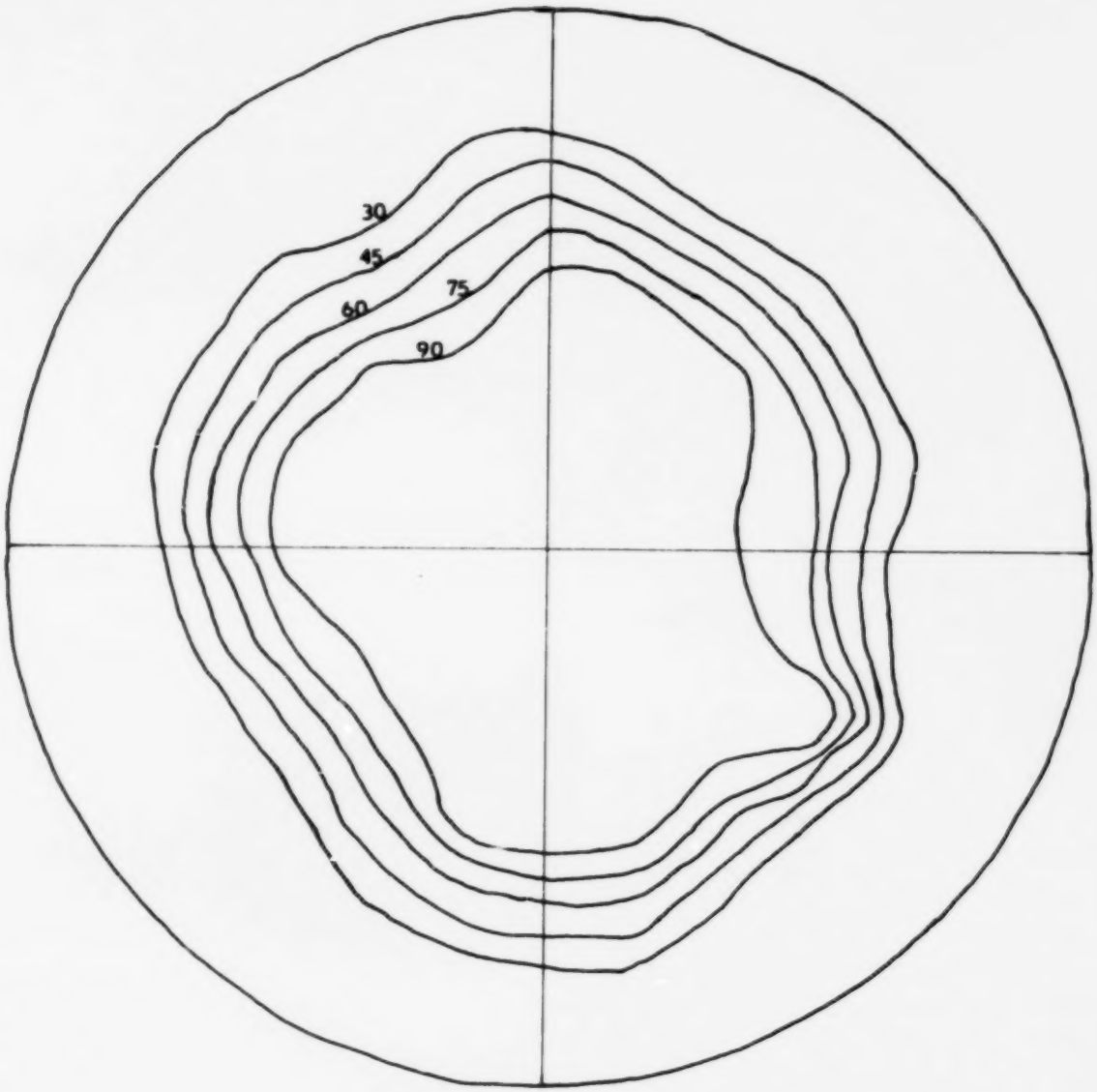


FIGURE 3-19

NO_x (ppm)

EXHAUST CONCENTRATION MAP

TF 30 ENGINE MAXIMUM CONTINUOUS POWER

source: NAFEC

Rdg. No. 17

SET 1422 03 0275

The measured concentration at each point was then weighted by the mass flow at each point and the average mass weighted concentration for each measured exhaust gas constituent was determined using the relationship:

$$\text{Mass weighted average concentration} = \frac{\sum_{1}^{n} C_n \rho_n V_n}{\sum_{1}^{n} \rho_n V_n}$$

where C_n is the concentration of the pollutant specie at each point, and $\rho_n V_n$ is the mass flow at each point.

The mass weighted average concentrations are presented in Table 3-3 along with the area weighted concentrations. The oxides of nitrogen averages at idle power are based on 92 data points; the other gas concentrations are based on all 121 data points. The mass flow weighted average concentrations are less than the area average weighted concentrations. This occurs because the mass flow is greater in the outer parts of the plume where the pollutant concentrations are lower.

A more realistic comparison of area weighted and mass flow weighted data can be made by calculating emission indices using the carbon balance technique described in Section 2.5. The emission indices determined by the two methods agree very well except for the hydrocarbon indices at approach and maximum continuous power. These differences of up to 10% were the result of unusually high hydrocarbon readings in the periphery areas apparently caused by hangup in the sampling probe. However, the emission indices for hydrocarbons at these two conditions were so low as to make the differences of little importance.

The above problem is evident from an examination of the consistent level of hydrocarbons measured in the traverses for approach and maximum continuous power. These data are listed in Appendix II. It is apparent that hydrocarbon hangup in the sampling system caused a near constant

background level to be recorded over the exhaust cross section. Measurement of hydrocarbons at low levels requires constant checks of sample line cleanliness so that no bias is put on the data. The check may be made by passing zero hydrocarbon calibration gas through the entire system and comparing the reading thus obtained with the zero setting obtained by injecting the zero gas directly into the hydrocarbon analyzer.

3.3.3 Total Emission Rates Calculated by Different Methods

The total emission rates of each pollutant in pounds per hour can be calculated from the mass weighted average concentrations shown in Table 3-2 in several ways. First, the rates can be calculated from the emission indices in Table 3-3 and the measured fuel flow rates shown in Table 3-1.

$$\text{Emission rate (\#/Hr.)} = \text{Emission Index (\#/K\# fuel)} \times \frac{W_F}{1000}$$

where: W_F = measured fuel flow rate (#/Hour)

The emission rate can also be calculated from the mass weighted average concentration (Table 3-2) and the exhaust flow rates (Table 3-1).

$$\text{Emission rate (\#/Hour)} = \frac{ppm}{10^6} \times \frac{MW}{29} \times W_E \times (3600)$$

where: W_E = Exhaust gas flow rate (#/sec.)

MW = Molecular weight of exhaust constituent (16 for THC, 28 for CO and 46 for NO_x)

ppm = Concentration of exhaust constituent in parts per million

W_E can be based on either measured bellmouth air flow and fuel flow or $\overline{\rho V}$ data.

Table 3-4 compares the emission rates as calculated by the different methods. The emission rates calculated from the emission indices and fuel flow rates are from 10 to 20% higher than those calculated from the mass flow weighted average concentrations and exhaust volumes calculated from $\overline{\rho V}$ at the nozzle plane. Substituting the exhaust volume based on bellmouth

SET 1422 03 0275

TABLE 3-2 POLLUTANT CONCENTRATIONS IN TF-30 EXHAUST DETERMINED BY TRAVERSE TESTS

Power Setting	THC ppm-C	CO ppm	CO_2 %	NO_x ppm
Area Weighted Average Concentration				
Idle	71.0	163.0	0.58	(3.4)*
Approach	13.2	66.8	0.85	12.9
Max.Cont.Power	10.5	18.1	1.35	45.3
Mass Flow Weighted Average Concentration				
Idle	60.0	132.0	0.49	(2.9)*
Approach	12.2	57.5	0.73	11.2
Max.Cont.Power	10.4	15.9	1.18	39.1

TABLE 3-3 POLLUTANT EMISSION INDICES AS CALCULATED BY CARBON BALANCE

Power Setting	#/K# Fuel THC	CO	NO_x
Area Weighted			
Idle	13.5	54.3	1.86*
Approach	1.77	15.6	4.96
Max.Cont.Power	0.89	2.69	11.0
Mass Flow Weighted			
Idle	13.55	52.1	1.88*
Approach	1.90	15.7	5.01
Max.Cont.Power	1.01	2.70	10.9

*Estimated

air flow and fuel flow results in even lower emission rates. The differences between rates calculated by the different techniques are greater than desirable. The differences can result from errors in fuel flow data, air flow data and traverse pressure and temperature data. There is insufficient information available to estimate the magnitude of these errors at the time the traverse runs were made. Since the emission indices agree well with those found in subsequent tests using other probes and analytical instrumentation, it is unlikely that errors in pollutant concentration data contribute significantly to the differences found.

TABLE 3-5 TF-30 EMISSION RATES CALCULATED BY DIFFERENT METHODS

Power Setting	NAFEC Rdg. No.	Fuel Flow #/Hr.	#/Hr. THC	CO	NO_x
Calculated From Emission Indices & Fuel Flow					
Idle	14	871	11.8	47.3	1.64
Approach	15	2230	3.95	34.8	11.1
Max.Cont.Power	17	5249	4.67	14.1	57.7
Mass Flow Weighted Avg. & Exhaust Volume (CV A)					
Idle	14		10.3	39.7	1.4
Approach	15		3.7	30.5	9.7
Max.Cont.Power	17		4.9	13.1	53.1
Mass Flow Weighted Avg. & Exhaust Volume (Bellmouth Air & Fuel Flow)					
Idle	14		9.10	35.1	1.23
Approach	15		3.51	28.9	9.18
Max.Cont.Power	17		4.53	12.0	48.9

4.0 PROBE MANIPULATOR

Comparative evaluations of multiple-point probes for gas turbine emissions measurement on actual gas turbines have been hampered by the run-to-run variation and the ambient temperature and humidity effects on the actual exhaust emissions. In order to overcome this difficulty, a special probe manipulator was designed, built and tested as part of this program. The probe manipulator was capable of exchanging and rotating three test probes in the TF-30 exhaust plane.

4.1 DESCRIPTION OF PROBE MANIPULATOR

The probe manipulator is depicted schematically in Figure 4-1. Three test probes were built into three 30-inch diameter rotatable steel pipe sections mounted on a welded framework which rode on flanged wheels. The entire probe holder assembly was mounted on trolley wheels, similar to the ones used in small overhead cranes, which rode on two I-beams supported a few inches above the test cell floor. The operation of the probe manipulator was remotely controlled from a console in the test cell control room during tests with the TF-30 engine at NAFEC.

Probe rotation was accomplished initially with a friction drive system. A gear head motor drove the lower sets of flanged wheels which supported each probe hoop through a chain and sprocket system. Angular position of the probes was monitored electrically by means of a 0-200 mv digital voltmeter which indicated the position of a 10-turn potentiometer driven by the gear motor actuator. The electrical signal was adjusted to give one millivolt change for a change of one degree in probe rotation.

The probe manipulator carriage was moved by a trolley drive motor which drove one set of the trolley wheels which rode on the I-beam. Micro-switches positioned along the forward I-beam rail were actuated by a cam mounted on the movable portion of the manipulator. Each micro-switch was connected to an indicator light on the manipulator control console. In operation, the probe manipulator carriage was positioned correctly when the appropriate indicator light was lit.

SET 1422 03 0275

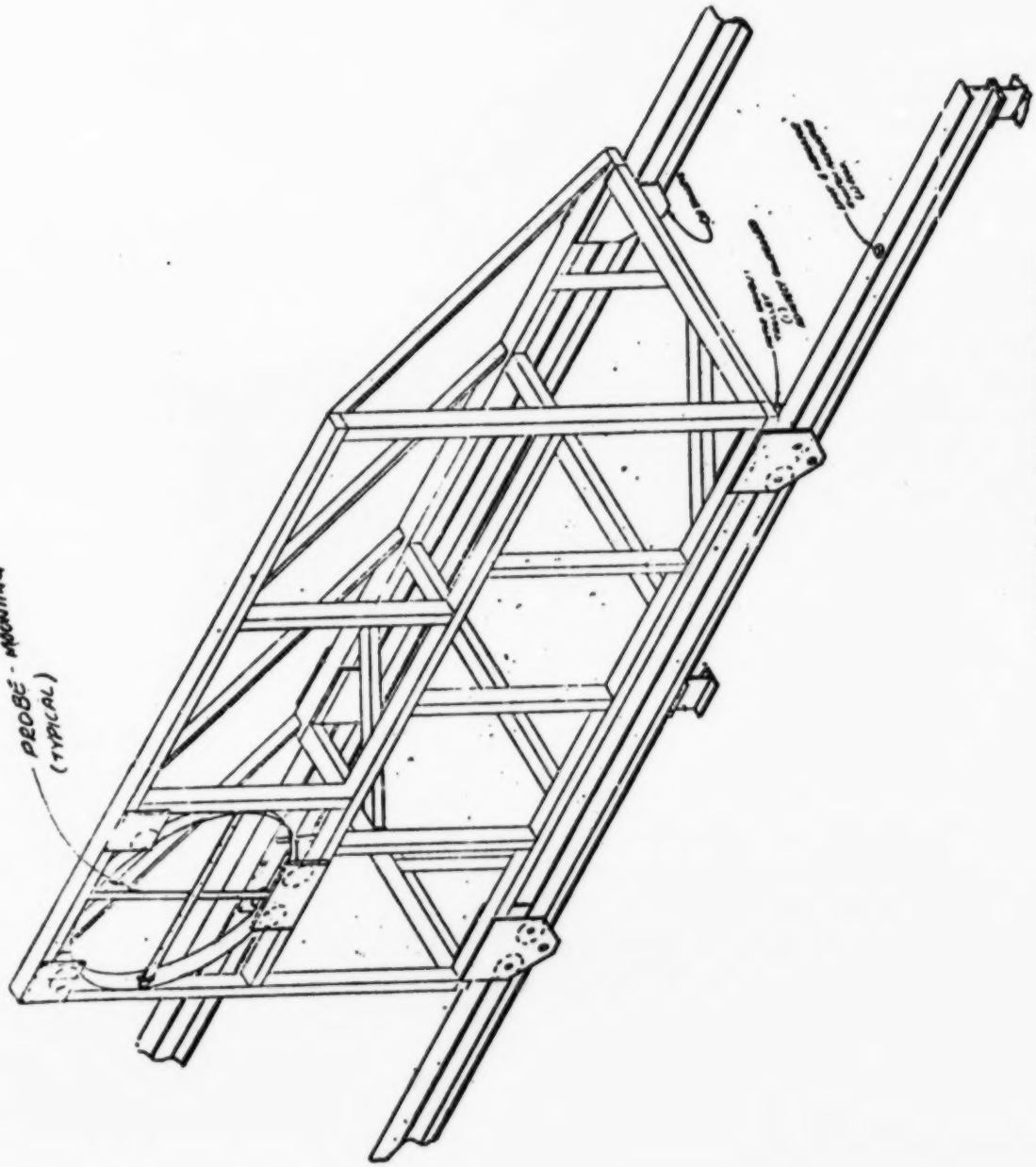


FIGURE 4-1 PROBE MANIPULATOR

4.2 MANIPULATOR INSTALLATION IN NAFEC TEST CELL

The probe manipulator was installed in the test cell 10 inches behind the engine exhaust nozzle. The TF-30 engine was mounted at a slight nose-up attitude on the test stand and the exit plane of the test nozzle attached to the TF-30 was raked back at a small angle from a perpendicular line to the engine thrust line. In order to match the probe manipulator attitude to the engine nozzle exit plane, the rearward rail of the probe manipulator was lowered and the forward rail was shimmed up so that the probes on the manipulator were parallel to the nozzle plane and centered on the nozzle diameter.

Heated, insulated sample lines were connected from each of the test probes to a manifold of heated solenoid valves. Remote selection of a test probe was made by switching on the appropriate solenoid which connected the probe to the sample line leading to the analysis instrumentation.

The heated sample lines connecting each probe to the solenoid manifold were dressed along the outside diameter of each probe hoop. In the "zero degree" position, only approximately 6 inches of sample line were exposed to the exhaust when changing probes. When the probes were rotated 90°, the sample lines lay exposed along a quarter-circle arc.

4.3 OPERATIONAL DIFFICULTIES WITH THE PROBE MANIPULATOR

In initial tests of the probe manipulator on gas turbine exhaust, the probe rotation functioned smoothly, but small irregularities in individual hoop shapes caused differential motion in the three hoops resulting in eventual misalignment. Since only the rotational attitude of the drive mechanism was measured as an angle position indication, misalignment was intolerable. The probe rotation mechanism was changed to a direct drive system using two loops of wire rope. The gear head motor now drove a capstan wrapped with several turns of wire rope which was then passed around the two adjacent hoops with a cable clamp bolted through each hoop. The third hoop was driven by a second loop of wire rope which passed over the second and third probe hoops. This modification completely eliminated the test probe misalignment problem.

The probe carriage drive which positions the three probes behind the engine functioned adequately at idle power, but not at approach power (40%). The drag force on the support structure between each probe ring unweighted the trolley drive mounted on the front rail so that the drive wheels slipped on the rail. The trolley drive was moved to the rear rail where the friction force on the drive wheel now increased with increasing drag load on the manipulator structure. The alignment of all the trolley wheels was adjusted so that the trolley drive was weighted sufficiently to allow probe manipulator operation when the engine was not running. With this modification, the carriage drive was operable up through cruise power. Further testing and development of the probe manipulator was not possible because the test cell was scheduled for other test programs. The drag force on the structure when the probe manipulator is between probes is very large due to exposing the flat plate area of the flanged wheels and their brackets to the engine exhaust. The addition of aerodynamic fairings and afterbodies would reduce this drag considerably. An actuator system using wire rope similar to that used for probe rotation would improve the carriage movement and give smooth, positive positioning of the probe carriage.

4.4 DESCRIPTION OF TEST PROBES

Four probes were fabricated for test with the probe manipulator. Design sketches for the test probes are shown as Figures 4-2, 4-3, 4-4 and 4-5. The probe illustrated in Figure 4-2 has twelve sample points on orthogonal arms and is designated as the twelve point cruciform in the following discussions. The sample points are located at centers of equal areas based on the 25-inch TF-30 nozzle diameter. An additional pluggable hole is located at the center of the probe. Figure 4-3 illustrates a probe built to FAA specifications. It has twelve sample points located on four sides of a square rotated 45° (diamond). The average sample point distance from the engine nozzle center corresponds to 63% of the nozzle radius and is referred to as the diamond probe. This probe was developed by locating the three holes in each leg at an average tailpipe radius that would produce the average exhaust concentrations as determined from the detailed traverse tests. Figure 4-4 shows a cruciform probe with a spiral hole pattern. The holes are at centers of equal area.

SET 1422 03 0275

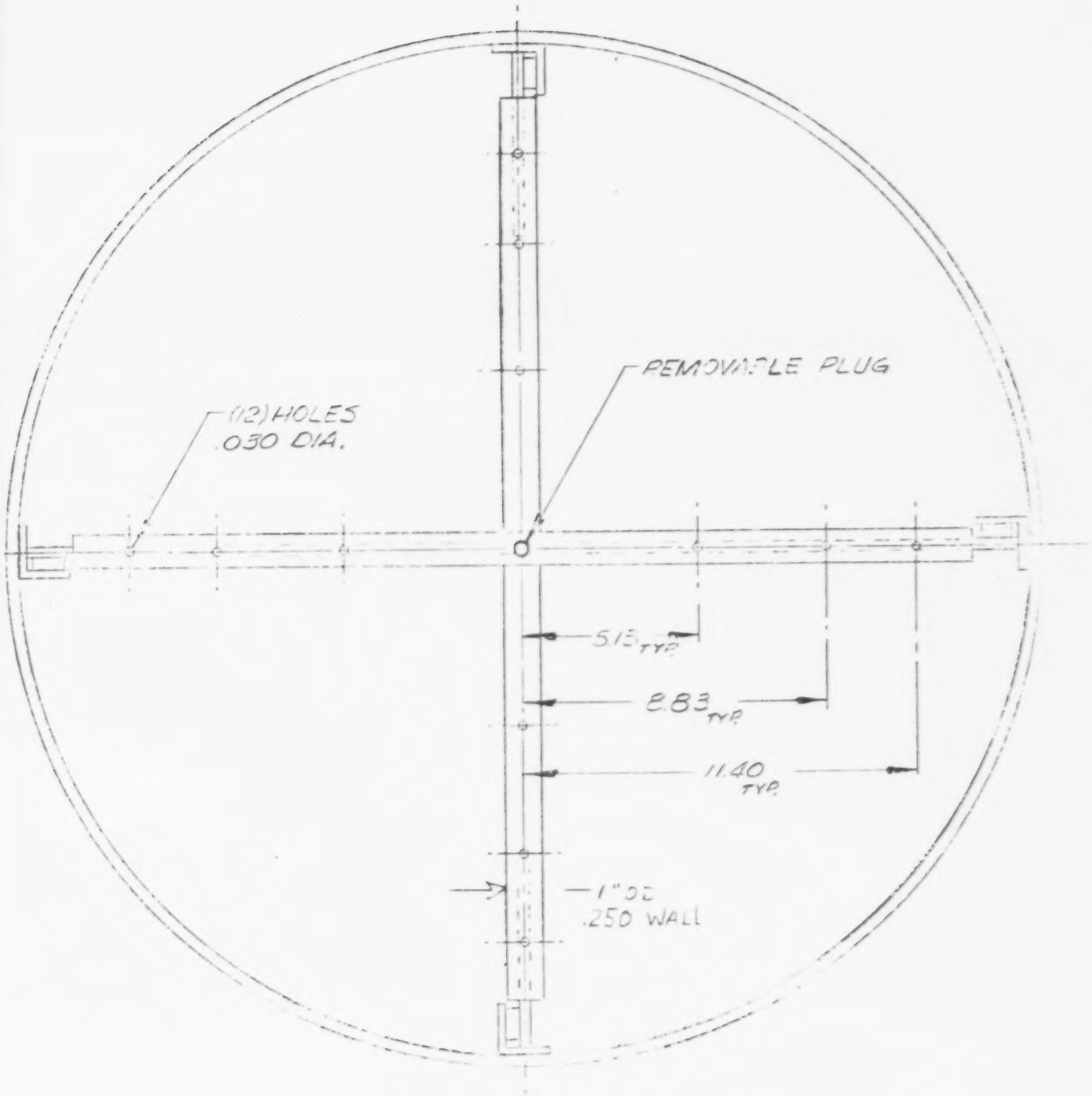


Figure 4-2

EPA
12 POINT CRUCIFORM PROBE

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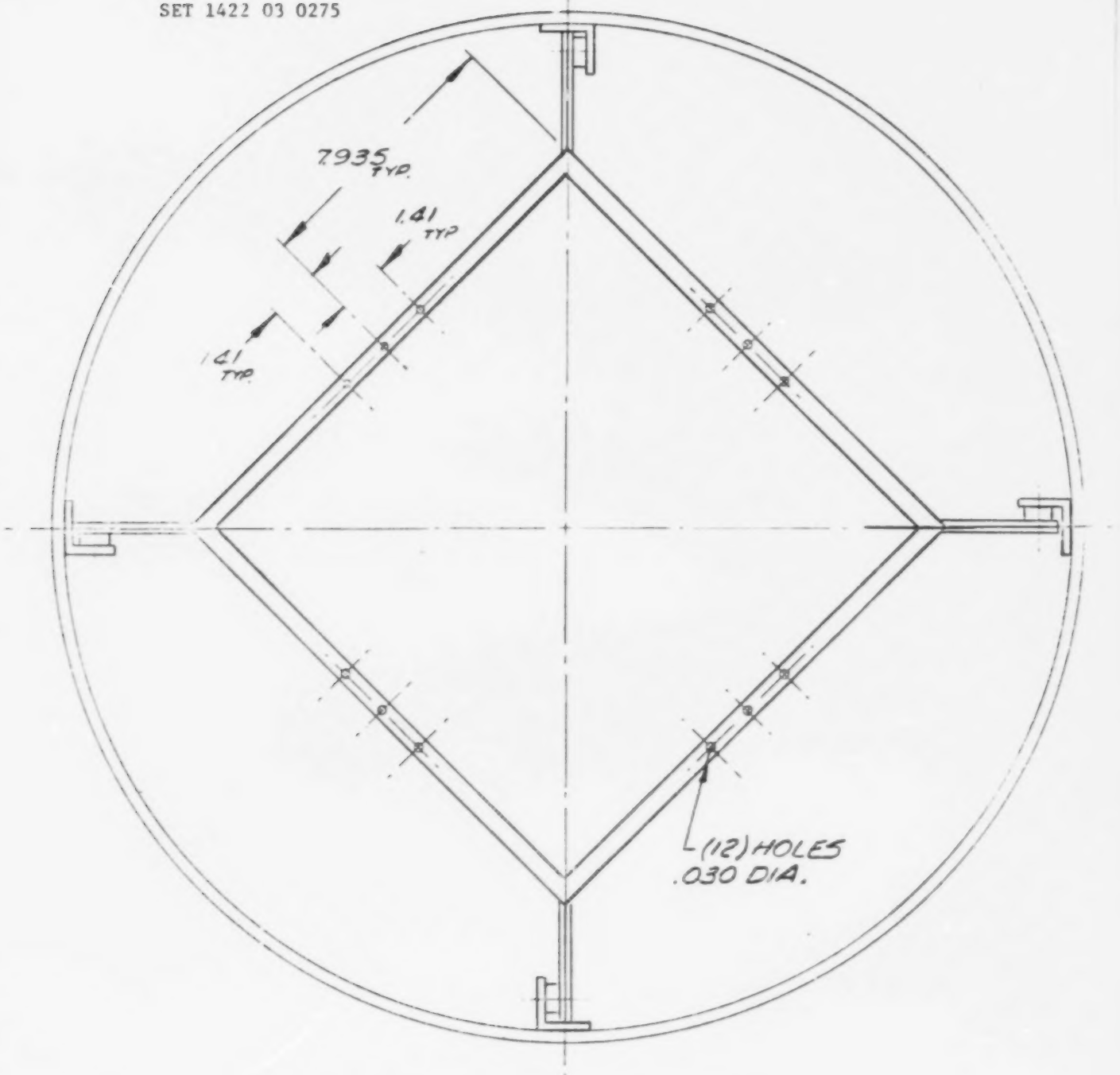

Figure 4-3

12 POINT DIAMOND PATTERN PROBE

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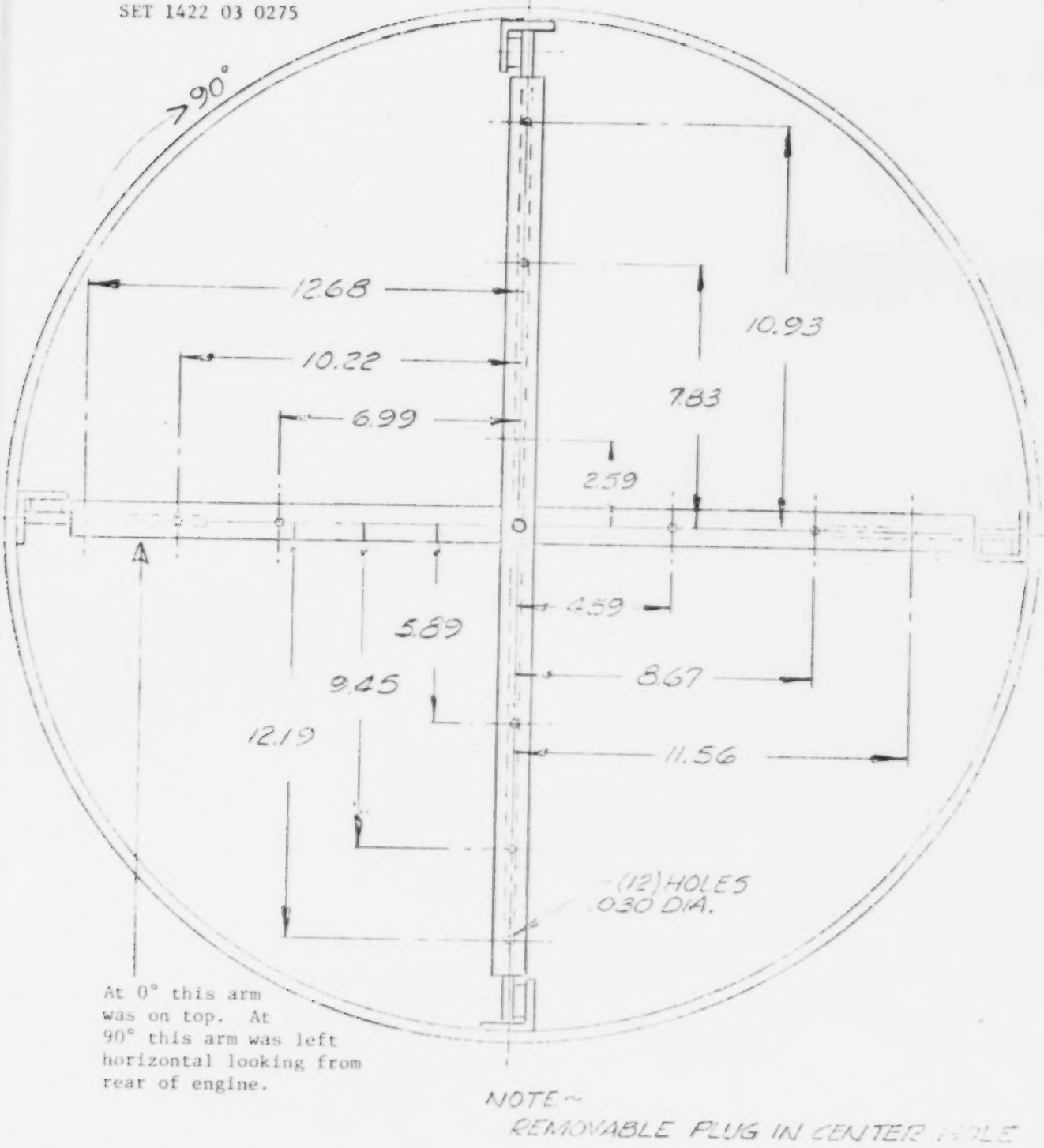

Figure 4-4

12 POINT CRUCIFORM FLOW
SPIRAL HOLE PATTERN

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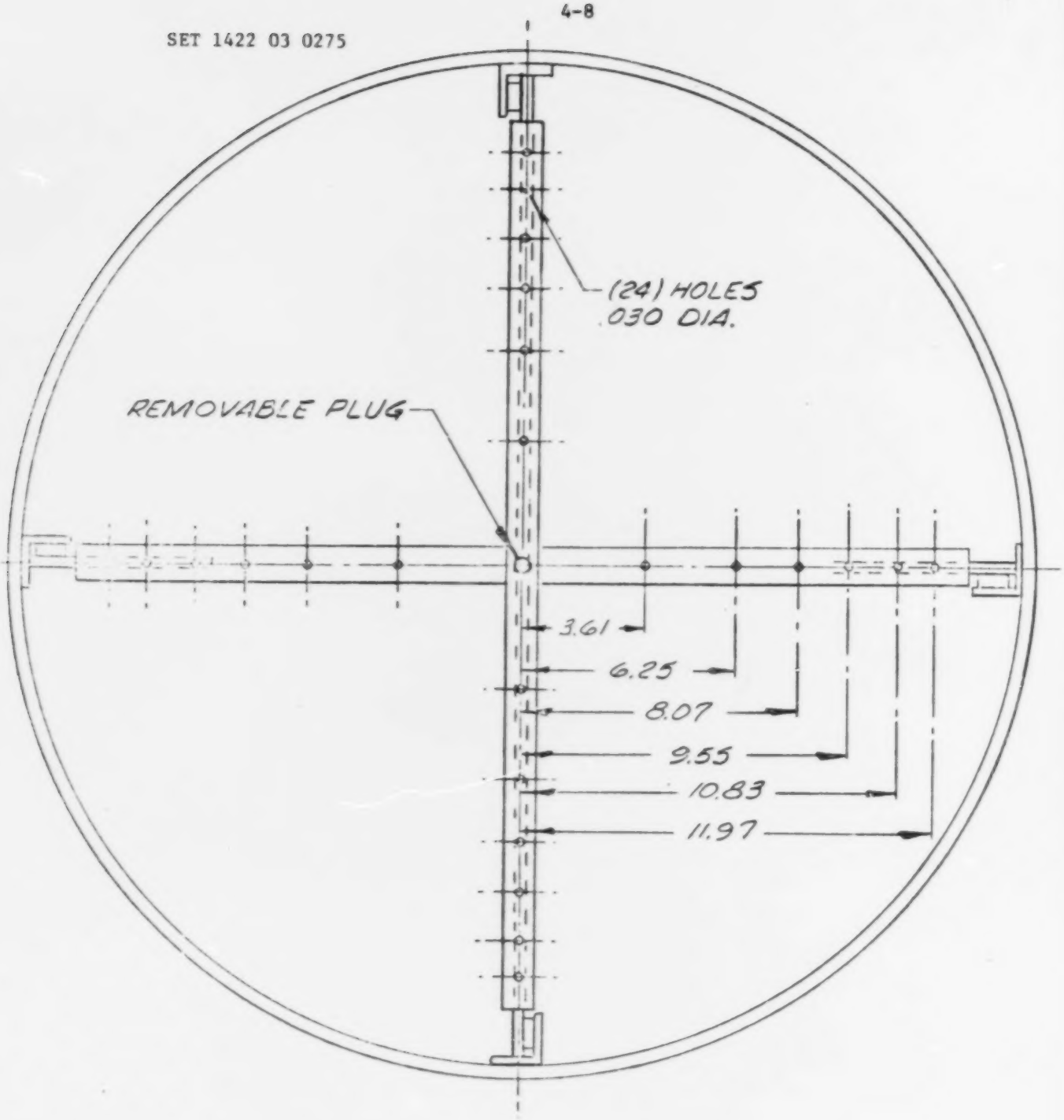


Figure 4-5

24 POINT CRUCIFORM PROBE

This pattern was developed by Pratt and Whitney Aircraft and is referred to as the twelve point spiral probe. A fourth test probe (not tested) is shown in Figure 4-5. It has twenty-four sampling holes at centers of equal area based on the 25-inch TF-30 nozzle diameter and a pluggable center hole.

The probes are made of heavy wall stainless steel tubing welded together. The three cruciform probes have the connection to the sample line at the center of the probe where the four arms are manifolded together. The sample line is connected to the diamond probe at one of the corners.

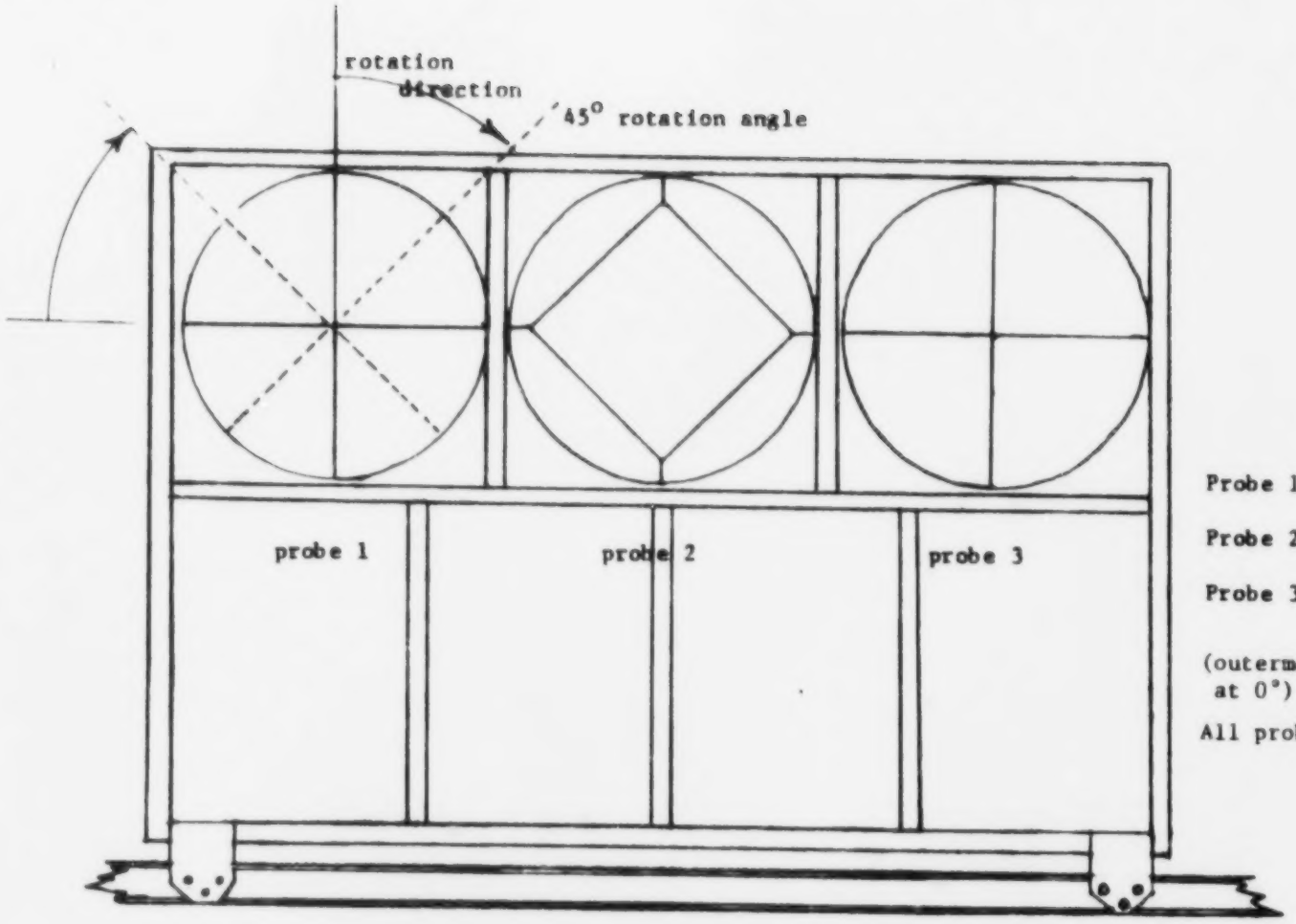
4.3 DESCRIPTION AND RESULTS OF PROBE TESTS USING THE PROBE MANIPULATOR

Three of the multiple point sampling probes were tested using the probe manipulator. The three probes were arranged on the manipulator as shown in Figure 4-6. Probe 1 was the twelve point cruciform; Probe 2 was the diamond; and, Probe 3 was the twelve point spiral. The probes are shown in the 0° position. In this position, the outermost hole of the spiral pattern probe was on the upper vertical arm (Probe 3).

Readings of emissions were taken at 15° increments from 0° to 90°. Most of the data were taken at idle power, but data were also taken at approach and cruise power. During one continuous run at idle power, samples were collected using the cruciform and spiral probes with and without the center hole. Data were collected at 30° rotation intervals.

The data taken with the multiple point probes on 30 September and 3 October are listed in the Probe Data Inventory (Appendix II). Engine Performance Data for these tests and all reported tests are included as Appendix III. Data taken on 12 September were not augmented with engine data and so were omitted from this report.

The concentration measurements at various angular positions for the three test probes are plotted in Figure 4-7, 4-8 and 4-9. These three figures represent three sets of tests on three separate days. The measured concentrations vary somewhat due to temperature, humidity, and small changes in engine power setting. However, the pattern of measured concentrations at the various angles is constant throughout for each probe.



Probe 1. 12 pt. cruciform
Probe 2. NAFEC diamond
Probe 3. 12 pt. P&W spiral

(outermost hole on top at 0°)

All probes shown at 0°

PROBE MANIPULATOR
Looking Aft

Figure 4-6

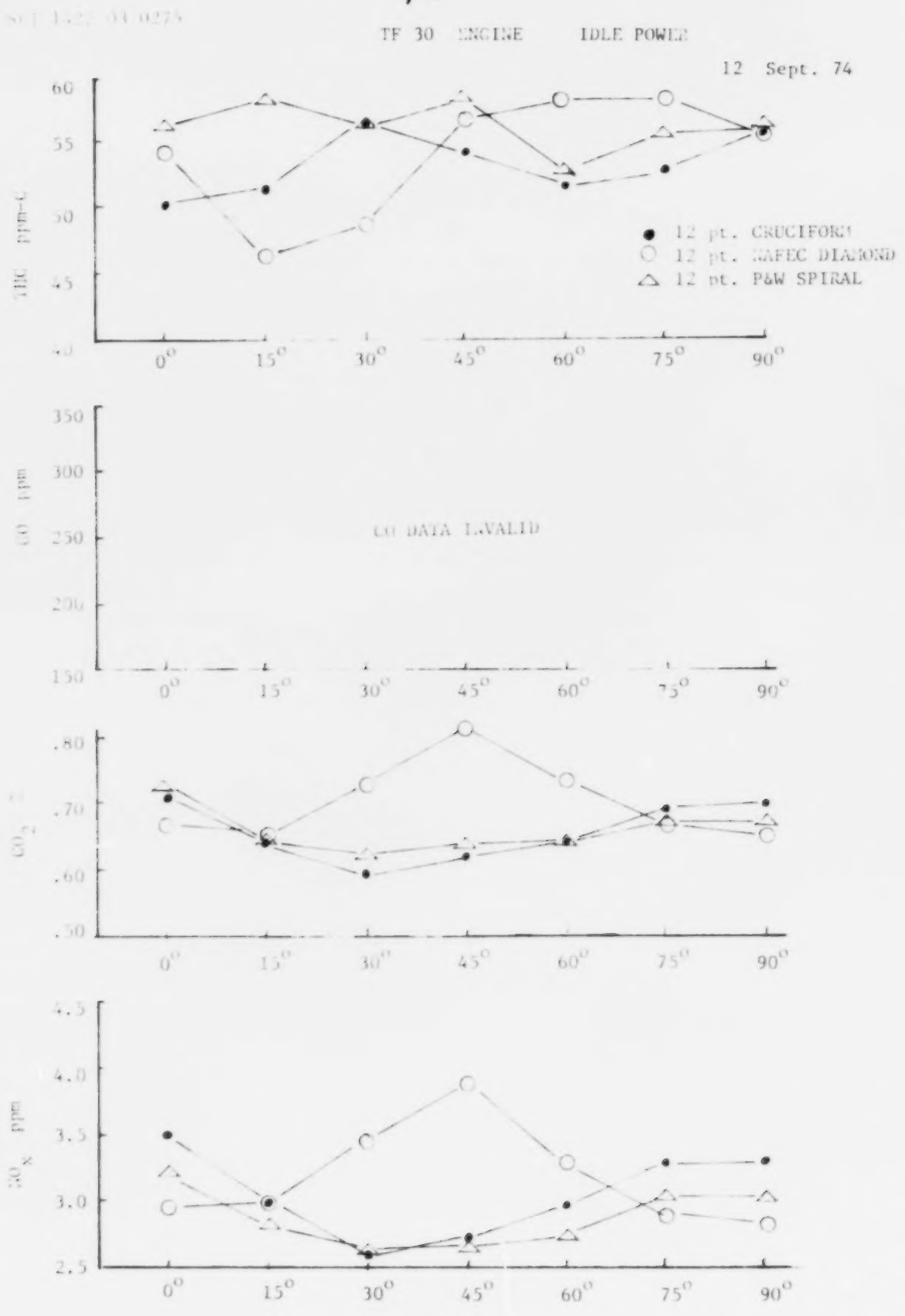


Figure 4-7
Measured Concentrations With Three Probes At Various Angles

SET 1422 03 0275

30 Sept. 74

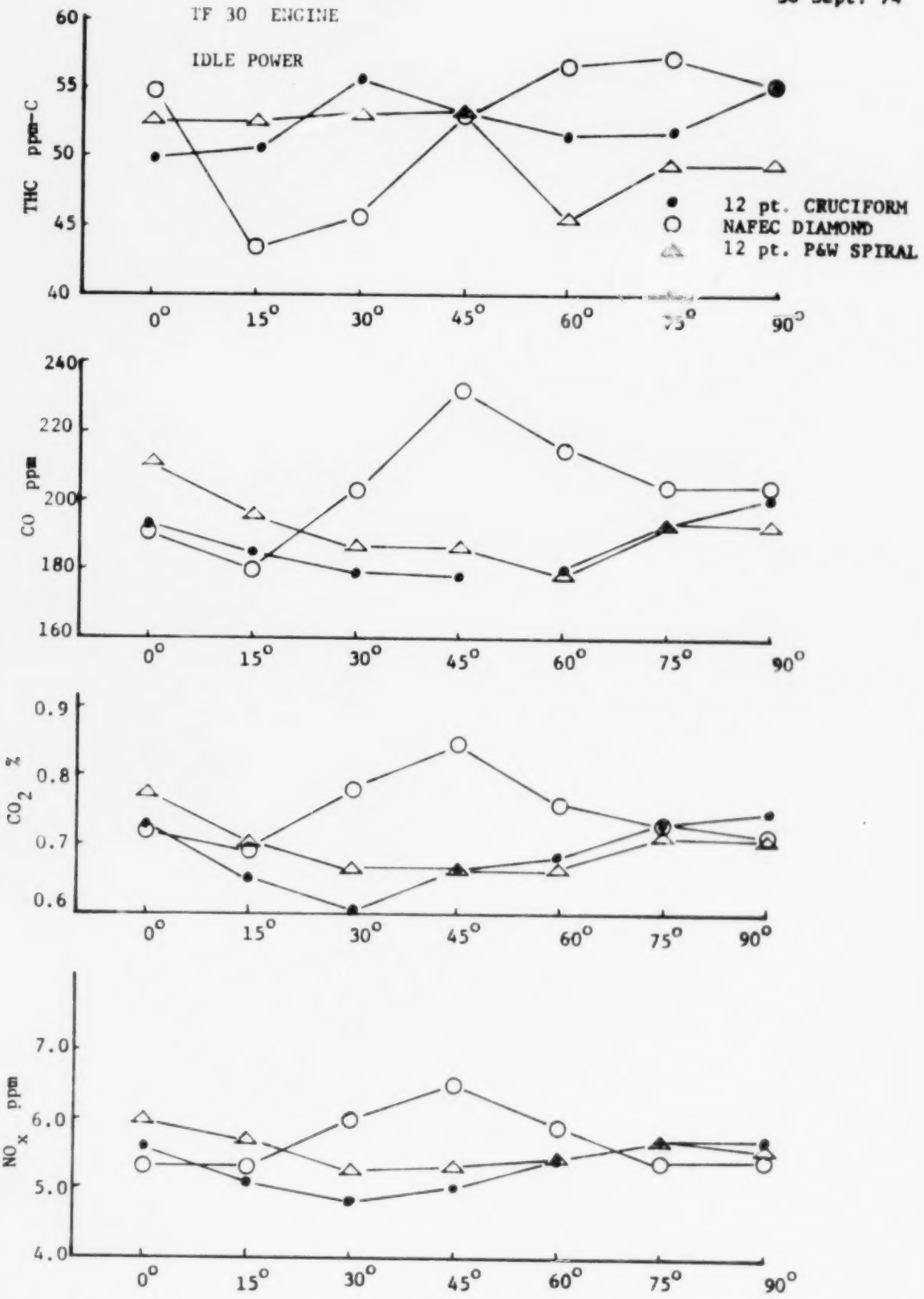


Figure 4-8
Measured Concentrations With Three Probes At Various Angles

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TF 30 ENGINE

3 Oct. 74

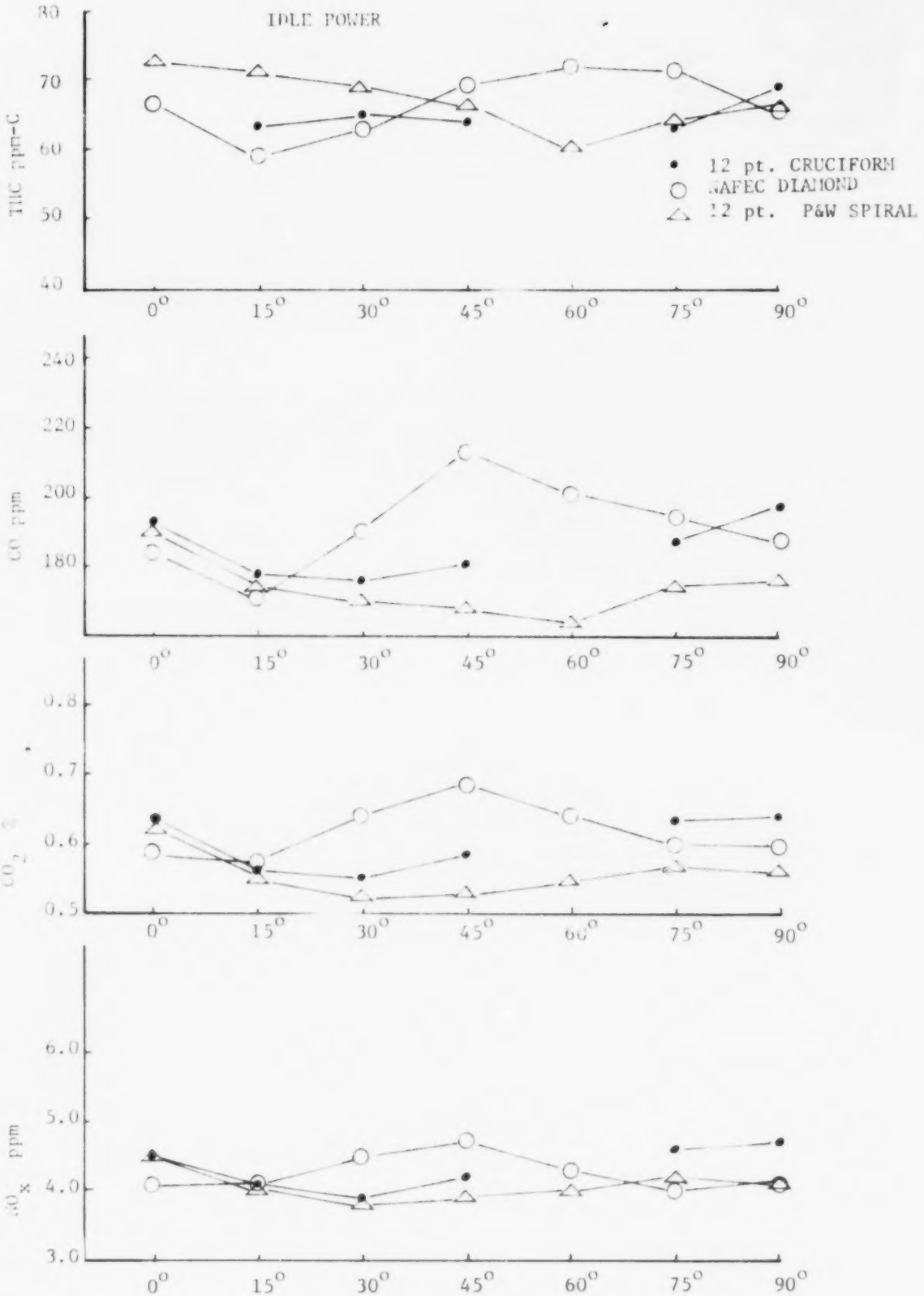

Figure 4-9
Measured Concentrations With Three Probes At Various Angles

The twelve point cruciform and the twelve point spiral probes gave similar results with the measured concentrations of CO, CO_2 and NO_x being highest at 0° and 90° and concentrations passing through a minimum from 30° to 45°. Maximum changes were approximately 10% over the range of angles for these two probes. The diamond probe received maximum CO, CO_2 and NO_x concentrations at a rotation angle of 45°, and progressively less concentrations in either direction away from 45°. Up to 16% variation in concentrations were observed with this probe. The hydrocarbon data followed an irregular pattern with probe rotation. However, the patterns were reproducible from day to day.

The effect on concentrations of exhaust components of adding the center hole is illustrated in Figures 4-10 and 4-11. The measured concentrations of CO, CO_2 and NO_x increased for both the cruciform and spiral probes with the addition of the center hole. This held true over the range of probe orientation from 0° to 90°. The hydrocarbons for the spiral probe also increased at all angles measured, but the hydrocarbon concentrations measured with the center holed twelve point cruciform increased at 0° but decreased at 30° and 60°.

4.6 EVALUATION OF TEST PROBE DATA

The purpose of the probe tests just described was to evaluate how well each probe and probe angle provided a representative sample of engine exhaust at the test condition. Based on this evaluation, probe type and position could be recommended for performing standard or reference emissions tests on a TF-30 engine.

The traverse tests described in Section 3.0 were performed in order to provide true emission concentrations and rates for use as targets to be achieved with the mixing probes. Unfortunately, there appear to be significant differences in emission rates between the runs during which the traverses were made and those in which the mixing probe tests were conducted. In addition, there appear to be day to day and within run variations in emission rates during the mixing probe tests. These variations

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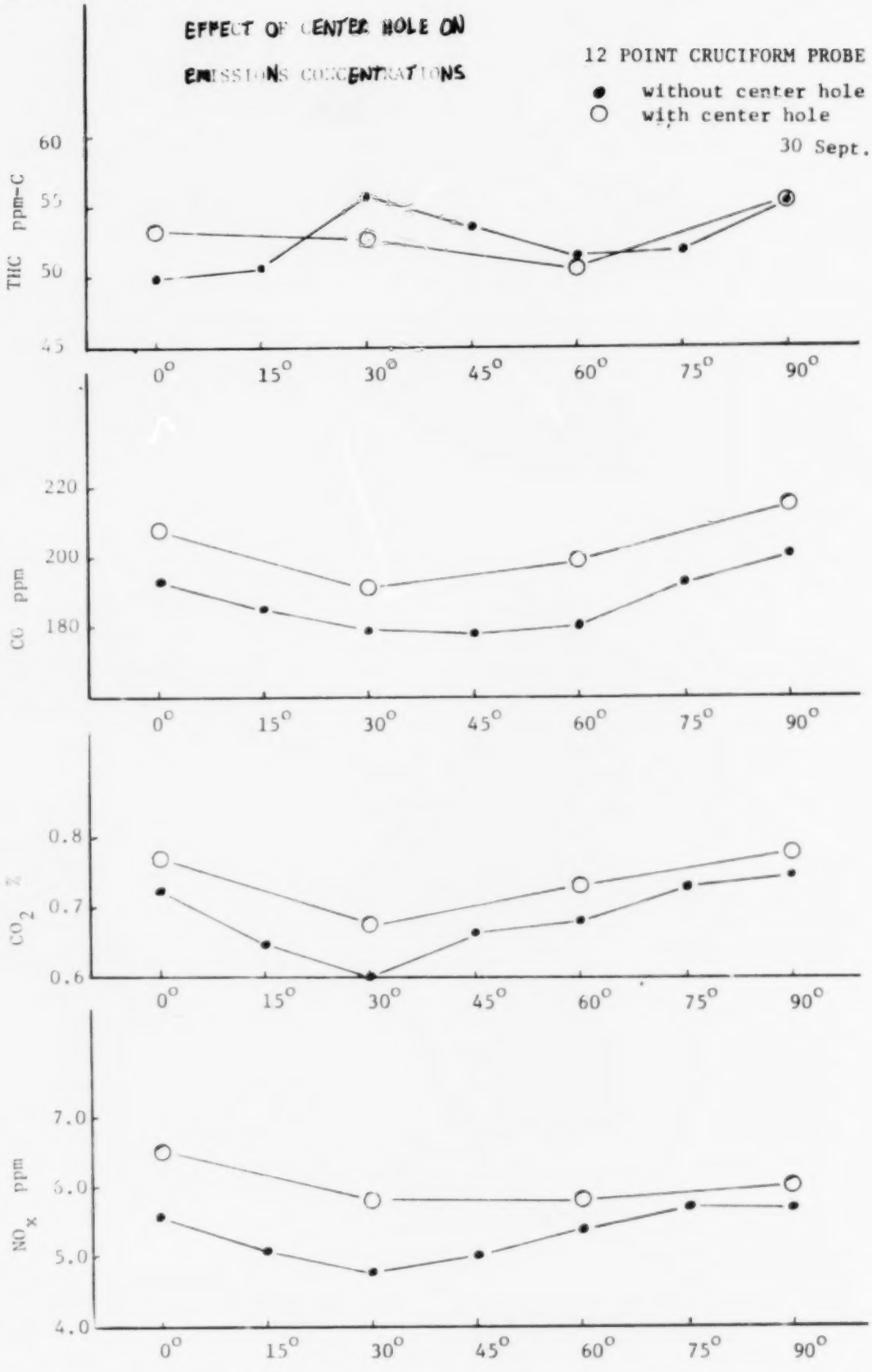

Figure 4-10

SET 1422 03 0275

12 POINT SPIRAL PROBE

EFFECT OF CENTER HOLE ON

EMISSIONS CONCENTRATIONS

△ without center hole
X with center hole

30 Sept. 74

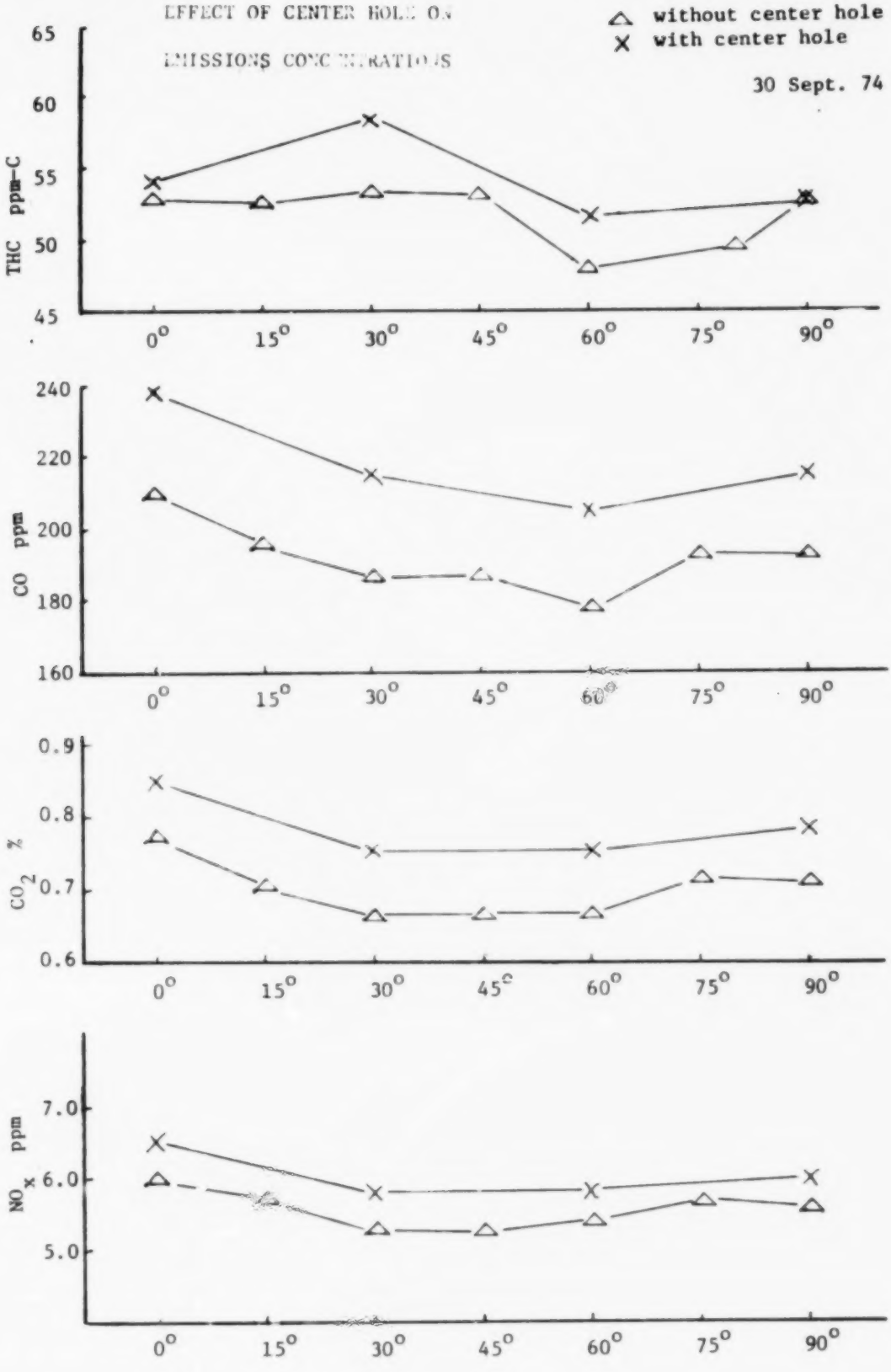

Figure 4-11

were of the same order of magnitude as the differences found from probe to probe and from one position angle to another. This makes it difficult to draw conclusions regarding probe design or probe position angle.

4.6.1 Run to Run Variations in Engine Conditions and Emissions Rates

Two sets of data are routinely collected which can be used as a measure of run-to-run variation. These are: (1) operating parameters of inlet air and fuel flows and, (2) emission concentrations measured with core probes. The core probes are located in the engine exhaust nozzle just aft of the turbine and measure the emissions from the primary gas stream only. Twelve sample holes (three on each of four chordwise stainless steel probes) are located in the core exhaust area. The four probes are manifolded together by a hoop of stainless steel tubing located outside the nozzle. Figure 4-13 depicts the core probe as installed in the TF-30 engine.

Because of its location in the core engine flow, the core probes register emission concentrations corresponding to lower air-fuel ratios than the actual overall engine air-fuel ratio. The core probes indicate a 2.5 times richer F/A ratio than the overall engine F/A. The actual engine operating point with respect to emissions during traverse tests and the later probe tests can be compared by referring to the core probe data obtained during these two sets of tests. The traverse tests were made on cold, dry January days while the probe tests were made on warmer days in September and October. The emissions indices can change significantly due to temperature and humidity effects. The temperature and humidity effects are being determined for this TF-30 engine by NAFEC in a separate program, however, the results are not available at this writing. In lieu of the correction factors for temperature and humidity for this engine, the core probe data obtained during both traverse tests and multiple point probe tests can be used to normalize the emissions rates in order to allow comparison of the emission indices obtained with the multiple point probes to the 'true' emission indices obtained from the traverse tests.

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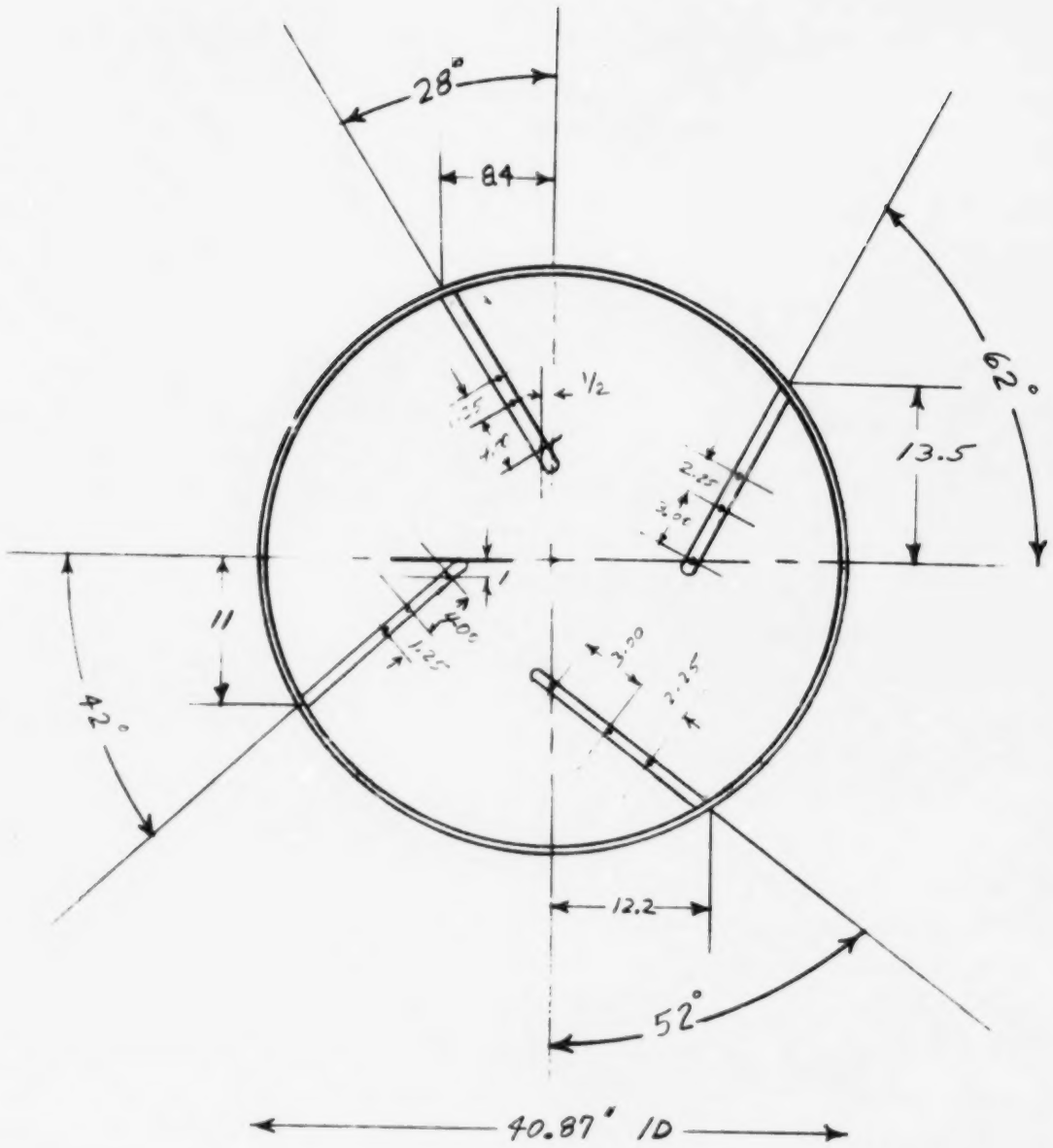

LOOKING UPSTREAM

HOLES SHOWN ON WRONG SIDE FOR CLARITY

NAFEC TF-30 CORE PROBE

Figure 4-13

The engine operating parameters of inlet air and fuel flow and the core probe emission data for the various test runs are compared in Table 4-1. Runs 14 to 17 were the traverse runs and Runs 272 to 280 were the probe test runs. The air-fuel ratios based on measured air and fuel flows are also included. The data in Table 4-1 clearly show the significant run-to-run and within run differences that occurred in exhaust composition. These differences are not readily explainable by differences in air or fuel flows.

The probe test data in Appendix II generally reflect the run-to-run differences in core exhaust concentrations. For example, the emission indices for CO and THC are much higher for all three probes in Run 275 than in Runs 272-4. The core exhaust data likewise show similar increases in CO and THC between these runs.

4.6.2 Evaluation Criteria for Test Probes

The air/fuel ratio calculated from the measured concentrations of combustion products has been suggested as a measure of probe performance[4]. Air/fuel ratios are calculated from exhaust composition (wet basis) by the following equation[4]:

$$A/F = \frac{207 - 2\,\frac{CO}{10^4} - CO_2}{\frac{CO}{10^4} + CO_2 + \frac{THC}{10^4}}$$

The A/F ratio is seen to be highly dependent on the CO_2 concentration. For the TF-30 engine the A/F ratio at idle is approximately $200/CO_2$ and at approach and maximum continuous power it is approximately $205/CO_2$. The simplified expressions yield values within ±1% of the values from the above equation.

In order for a probe to meet the A/F ratio criterion it must provide a sample with a CO_2 concentration representative of the overall exhaust average. Of greater importance, it must also provide a sample with representative concentrations of CO, THC and NO_x. This criterion can be evaluated by comparing the emission index for each pollutant to the true value. In this case the true value is assumed to be that derived from the traverse data described in Section 3.0.

TABLE 4-1 NAFEC CORE PROBE DATA

Date	Run No.	Power Setting	Inlet Air #/Sec.	Fuel Flow #/Hr.	CO_2 %	THC ppm-C	CO ppm	NO_x ppm	Meas. A/F	Meas. F/A	EPR
24 Jan.	14	Idle	76	870	1.74	234	505	14	314	.00317	1.0793
24 Jan.	14	Idle	76	870	1.76	234	505	14	314	.00317	1.0793
25 Jan.	15	Approach	141	2242	2.10	35	182	32	226	.00439	1.311
25 Jan.	15	Approach	141	2242	2.14	30	166	33	226	.00439	1.311
25 Jan.	15	Approach	141	2242	2.08	24	163	35	226	.00439	1.311
25 Jan.	15	Approach	141	2242	2.26	24	158	35	226	.00439	1.311
28 Jan.	16	Cruise	204	4786	2.86	2	48	82	153	.00645	1.738
28 Jan.	16	Cruise	204	4786	2.98	2	50	84	153	.00645	1.738
28 Jan.	16	Cruise	204	4786	2.89	14	44	86	153	.00645	1.738
31 Jan.	17	Max.Cont.Power	218	5356	3.54	11	38	110	147	.00666	1.9058
31 Jan.	17	Max.Cont.Power	218	5356	3.12	12	41	110	147	.00666	1.9058
31 Jan.	17	Max.Cont.Power	218	5356	3.32	15	40	110	147	.00666	1.9058
30 Sep.	272	Idle	80	918	2.13	161	534	20	314	.00317	1.084
30 Sep.	273	Idle	80	918	1.94	161	527	25	314	.00317	1.081
30 Sep.	274	Idle	79	891	1.85	153	520	17	319	.00313	1.082
3 Oct.	275	Idle	77	874	1.86	228	582	38	317	.00316	1.081
3 Oct.	276	High Idle	88	1013	1.95	186	508	41	313	.00321	1.098
3 Oct.	277	Higher Idle	97	1150	1.95	140	424	48	304	.00330	1.099
3 Oct.	278	Approach	-	2257	2.24	27	168	65	-	.00649	1.681
3 Oct.	279	Cruise	204	4760	3.00	6	53	127	154		1.853
3 Oct.	280	Max.Cont.Power	219	5814	3.18	3	40	171	136		

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4.6.3 Evaluation of Probes and Probe Positions

A comparison of emission indices for the three probes and the several probe positions to the indices derived from traverse data requires application of the normalization procedure referred to in Section 4.6.1. If this is not done, the run-to-run variations, which are greater than probe-to-probe variations, will completely mask any differences due to probes or probe positions.

The probe test data were normalized by applying a correction factor equal to the ratio of the core emission index during the corresponding traverse run to the core emission index during the probe test run. In normalizing the probe test data, it was assumed that the core emissions were constant during each test run. A more accurate normalization would require core data for each probe test point, but this was not available. The normalization and subsequent comparison was limited to CO and THC because of missing NO_x data points in the traverse runs and probable erroneous NO_x data for some core runs.

The normalized THC and CO emission indices in tests at idle power setting conducted on 30 September and 3 October are presented in Table 4-2. It is quite apparent that the normalization substantially reduced the run-to-run differences shown in Appendix II. Each of the three test probes yielded indices which were reasonably close to the indices calculated from traverse data for both THC and CO at most probe angles. In fact, most probe indices differ from the traverse indices by less than 10%. When the cruciform and spiral probes were positioned between 15° and 45°, the indices ranged up to nearly 20% higher than the traverse indices. This can be explained by the non-symmetry of the pollutant isopleths as illustrated in Figures 3-12 to 3-14.

The addition of the center hole to the twelve-point curciform and spiral probes had little effect on the emission indices. The hydrocarbon indices were up to 5% lower with the center hole open, but changes in the carbon monoxide indices were within experimental error.

Most of the A/F ratios calculated from test probe data at idle power setting were within 10% of the values calculated from measured air and fuel flows (see Appendix II). This applies to all three test probes. The

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TABLE 4-2 EMISSION INDICES NORMALIZED WITH CORE PROBE DATA
IDLE POWER

		Emission Index (#/1000# Fuel)					
		Without Center Hole				With Ctr Hole	
		THC		CO		THC	CO
Probe	Angle	9/30	10/3	9/30	10/3	9/30	9/30
12 pt.Cruciform	0	13.5	12.8	59.3	54.9	12.6	53.7
	15	15.3	13.7	63.1	56.6	-	-
	30	18.2	14.2	66.2	56.8	14.2	56.4
	45	15.9	13.2	59.5	55.0	-	-
	60	14.9	-	59.1	-	12.6	54.2
	75	14.0	12.1	59.0	52.9	-	-
	90	14.6	13.0	60.0	54.9	13.0	55.5
NAFEC Diamond	0	15.1	13.8	56.7	55.8	-	-
	15	12.4	12.5	55.3	53.1	-	-
	30	11.5	11.9	55.4	53.1	-	-
	45	12.4	12.2	58.6	55.5	-	-
	60	14.7	13.6	60.1	56.0	-	-
	75	14.2	14.3	57.5	57.7	-	-
	90	14.0	13.3	58.9	56.0	-	-
PSW Spiral	0	12.4	14.2	56.1	54.6	11.5	55.6
	15	13.5	15.6	57.5	56.4	-	-
	30	14.5	16.0	57.8	57.5	14.0	56.5
	45	14.5	15.1	57.8	56.3	-	-
	60	12.4	13.3	55.6	53.4	12.6	54.3
	75	12.6	13.7	55.6	54.6	-	-
	90	12.6	14.2	56.1	55.9	12.2	54.5
Traverse Average *		13.5		54.3			
Traverse Mass Wtd. Average *		13.6		52.1			

* From Table 3-3

run-to-run and within run variations discussed previously produce an uncertainty in true A/F ratios at the time specific probe data points were sampled. The addition of the center hole to the cruciform and spiral probes resulted in calculated A/F ratios definitely lower than the true values. This means that the central core area of the plume was being sampled in greater volume. The samples would not necessarily be representative of the total exhaust.

Insufficient data are available to draw conclusions on the performance of the test probes at power settings other than idle. There is evidence that as the load increased the difference between measured and calculated A/F ratios also increased. If this is real, it would imply that the sampling holes are too close to the center of the nozzle plane, and the outer portions of the plume are being sampled in too small a proportion.

4.6.4 Discussion of Probe Performance Results

The probe tests showed relatively small differences among emissions indices and A/F ratios calculated from data obtained for different probes and probe angles. This implies that probe position and configuration are not especially important in determining engine emission rates. This may well be true for the TF-30 engine because of its symmetrical emission concentration pattern. Another important factor is the ratio betweeen concentrations of pollutants (THC, CO and NO_x) and CO_2. This ratio remained relatively constant except for the very outer regions of the plume. Therefore, the emission indices change little from point-to-point in the major part of the plume, and the location of the sampling points are not critical for the TF-30.

On the other hand, previous data collected for the JT-8D engine showed substantial changes in ratios and emissions indices from point to point in the plume. This makes probe configuration and position of much greater importance for the JT-8D than the TF-30. Thus, the fact that a specific probe design gave acceptable results when sampling exhaust from a TF-30, in no way assures satisfactory performance when used in tests on other engine types.

5.0 REFERENCES

1. Souza, A.F. and Reckner, L.R.,
"Variability in Aircraft Turbine Engine Emissions Measurements,"
Environmental Protection Agency Report; EPA-460/3-74-006, January, 1974.

2. "Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines,"
ARP 1256, Society of Automotive Engineers, January 10, 1971.

3. "Aerodynamic Measurements"
Gas Turbine Laboratory, Massachusetts Institute of Technology,
1959.

4. Dieck, R.H.,
"Gas Turbine Emission Measurment Uncertainty,"
ISA Conference, October, 1974.

APPENDIX I

TRAVERSE TEST DATA

NOMENCLATURE USED IN APPENDIX I

P_{T_8} - Total pressure 2 inches behind exhaust nozzle exit plane in inches of water or mercury as appropriate relative to barometric pressure

P_{S_8} - Static pressure 2 inches behind exhaust nozzle exit plane in inches of water relative to barometric pressure

T_{T_8} - Total temperature of exhaust gas at a point 2 inches behind exhaust nozzle exit plane (^{o}F)

$\frac{P_o}{ABS}$ - Total pressure at station 8 in absolute units (lbs/ft^2)

$\frac{P_s}{ABS}$ - Static pressure at station 8 in absolute units (lbs/ft^2)

$\frac{T_{T_8}}{ABS}$ - Total temperature at station 8 in absolute units (^{o}R)

M - Mach number

T_s - Stream temperature - temperature of the gas stream at each point in absolute units (^{o}R)

Va - Speed of sound (ft/sec)

V - Velocity of gas stream at each point (ft/sec)

ρ - Gas density at each point ($slugs/ft^3$)

ρV - Product of density and velocity or essentially the mass flow ($slugs/ft^2$-sec)

THC - The measured concentration of total hydrocarbons in parts per million as methane

CO - The measured concentration of carbon monoxide in parts per million

CO_2 - Measured concentration of carbon dioxide in per cent

NO_x - Measured concentration of total oxides of nitrogen in parts per million

APPENDIX I

EXHAUST TRAVERSE DATA

TF-30-P1 Engine

NAFEC Reading No. 14 24 January 74

IDLE POWER

Average Engine Parameters during Reading No. 14 Idle Power

Air Inlet Dry Bulb Temperature - 43.9°F

Air Inlet Wet Bulb Temperature - 37.8°F

P_{T_7} - 2.40 in. Hg.

P_{T_4} - 50.6 in. Hg.

CIP_{total} - 30.24 in. HgA

CIP_{static} - 53.9 in. H_2O

Barometric Pressure - 30.27 in. Hg.

NOTE: Some data are missing. Numbers in parentheses have been estimated based on nozzle symmetry.

Position	P_{T_8} (in.H_2O)	P_{S_8} (in.H_2O)	T_{T_8} (°F)	P_o (Abs.) (lb./ft.^{2})	P_s (Abs.) (lb./ft.^{2})	T_{T_8} (Abs. °R)	Mach No. (M)	Stream Temp. T_S (°R)	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV Slugs/(ft.^{2} sec.)	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
1	40.2	.9	55	2351.8	2146.6	515	0.36	502	1098	399	.00250	.996	9	2.5	0.06	0.0
2	38.0	3.2	150	2340.3	2158.6	610	0.34	596	1196	409	.00211	.864	16.5	24	0.04	0.0
3	36.2	4.5	390	2330.9	2165.4	850	0.33	832	1413	461	.00152	.700	60	130	0.50	4.0
4	35.5	5.1	600	2327.3	2168.6	1060	0.32	1039	1579	504	.00122	.614	126	288	1.04	5.5
5	34.3	5.8	610	2321.0	2172.2	1070	0.31	1050	1588	491	.00121	.593	147	355	1.34	7.5
6	32.8	6.2	610	2313.2	2174.3	1070	0.30	1051	1589	475	.00121	.573	147	361	1.28	7.5
7	32.9	6.3	600	2313.7	2174.8	1060	0.30	1041	1581	473	.00122	.576	156	368	1.17	7.5
8	33.8	6.1	605	2318.4	2173.8	1065	0.30	1046	1584	483	.00121	.586	177	380	1.09	7.5
9	35.2	5.6	580	2325.7	2171.2	1040	0.32	1020	1565	493	.00124	.612	156	368	1.13	6.5
10	35.4	5.0	370	2326.8	2168.0	830	0.32	813	1397	447	.00155	.694	102	227	0.76	3.5
11	36.1	4.1	180	2330.4	2163.3	640	0.33	626	1228	402	.00201	.810	54	97	0.38	1.5
12	37.7	2.5	100	2338.8	2155.0	560	0.34	547	1146	394	.00230	.906	24	38	0.17	0.5
13	34.5	.5	60	2322.1	2144.5	520	0.34	508	1105	375	.00246	.924	15	6	0.43	0.0
14	38.7	1.0	60	2344.0	2147.2	520	0.36	507	1103	393	.00247	.971	15	2	0.06	---
15	38.2	3.1	165	2341.4	2158.1	625	0.34	611	1211	416	.00206	.857	15	25	0.04	---

APPENDIX I

(Continued)

EXHAUST TRAVERSE DATA

TF-30-P1 Engine

NAFEC Reading No. 14 24 January 74

IDLE POWER

Position	P_{T_8} (in.H_2O)	P_{S_8} (in.H_2O)	T_{T_8} (^oF)	P_o (Abs.) (lb./ft.^{2})	P_8 (Abs.) (lb./ft.^{2})	T_{T_8} (Abs.) (^oR)	Mach No. (M)	Stream Temp. T_S (^oR)	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV $\left(\frac{\text{Slugs}}{\text{ft.}^2 \text{ sec.}}\right)$	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPH Wet
16	36.5	4.4	165	2332.5	2164.9	625	0.33	612	1212	398	.00206	.821	51	130	0.52	---
17	36.6	5.1	595	2333.0	2168.6	1055	0.33	1033	1575	512	.00122	.627	120	204	0.78	---
18	35.4	5.8	630	2326.8	2172.2	1090	0.32	1069	1601	505	.00119	.598	159	410	1.54	---
19	34.0	6.0	630	2319.5	2173.3	1090	0.31	1070	1603	491	.00118	.582	189	436	1.37	---
20	33.8	6.2	610	2318.4	2174.3	1070	0.30	1051	1588	483	.00121	.583	189	429	1.42	---
21	34.8	6.1	610	2323.6	2173.8	1070	0.31	1050	1587	492	.00121	.595	192	455	1.42	---
22	35.2	5.6	560	2325.7	2171.2	1020	0.32	1000	1549	488	.00127	.618	192	468	1.50	---
23	35.3	5.0	370	2326.2	2168.0	830	0.32	813	1397	446	.00155	.693	126	299	0.99	---
24	36.0	4.1	210	2329.9	2163.3	670	0.33	656	1255	437	.00192	.840	72	149	0.4	---
25	38.4	2.4	210	2342.4	2154.5	670	0.35	654	1253	436	.00192	.837	39	68	0.2	---
26	20.7	---	50	2250.0	------	510	----	----	----	---	------	(.970)	16.5	10	0.1	---
27	37.6	2.3	120	2338.3	2153.9	580	0.35	566	1166	402	.00222	.892	18	26	0.1	---
28	36.3	3.9	120	2331.5	2162.3	580	0.33	568	1167	385	.00222	.856	39	97	0.4	(3)
29	36.2	4.7	500	2330.9	2166.5	960	0.33	940	1502	488	.00134	.656	91.5	246	0.99	(7.2)
30	35.3	5.4	540	2326.2	2170.1	1000	0.32	980	1534	486	.00129	.627	144	356	1.37	---
31	34.5	5.8	545	2322.1	2172.2	1005	0.31	986	1538	478	.00128	.614	180	367	1.37	---
31x	35.1	5.8	---	2325.2	2172.2	1070	0.32	1049	1587	498	.00121	(.608)	195	429	1.47	---
32	35.1	5.6	---	2325.2	2171.2	1070	0.32	1049	1587	499	.00121	(.608)	186	448	1.57	---
33	36.4	5.2	---	2332.0	2169.1	1070	0.33	1048	1586	513	.00121	(.608)	186	436	1.47	---
34	36.2	4.6	---	2330.9	2166.0	1070	0.33	1048	1586	516	.00121	(.650)	114	247	0.79	(6.5)
35	36.4	3.5	---	2332.0	2160.2	1070	0.33	1047	1585	527	.00120	(.790)	48	79	0.3	(2.5)
36	39.4	1.1	---	2347.7	2147.7	1070	0.36	1043	1582	568	.00120	(.900)	24	32	0.2	---
37	37.4	1.2	---	2337.2	2148.2	1070	0.35	1044	1583	553	.00120	(.970)	12	7	0.04	---
38	36.4	3.1	140	2332.0	2158.1	600	0.34	587	1187	397	.00214	.850	18	33	0.1	---
39	35.6	4.2	275	2327.8	2163.9	735	0.32	720	1314	427	.00175	.749	39	94	0.4	(5)
40	35.1	4.9	315	2325.2	2167.5	775	0.32	760	1350	430	.00166	.716	82.5	167	0.58	(7)

APPENDIX I

(Continued)

EXHAUST TRAVERSE DATA

TF-30-P1 Engine

NAFEC Reading No. 14 24 January 74

IDLE POWER

Position	P_{T_8} (in.H_2O)	P_{S_8} (in.H_2O)	T_{T_8} °F	P_o (Abs.) (lb./ft.^{2})	P_s (Abs.) (lb./ft.^{2})	T_{T_8} (Abs.) °R	Mach No. M	Stream Temp. T_s °R	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV Slugs/(ft.^{2} - sec.)	THC PPM_c Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
41		5.2	380	2324.2	2169.1	840	0.32	824	1406	444	.00154	.682	96	175	0.69	---
42	35.8	5.2	550	2328.9	2169.1	1010	0.32	990	1541	494	.00128	.631	144	310	1.08	8.0
43	35.5	5.0	450	2327.3	2168.0	910	0.32	892	1463	468	.00142	.664	144	310	1.18	8.0
44	36.4	4.5	300	2332.0	2165.4	760	0.33	744	1336	437	.00170	.742	90	196	0.69	5.0
45	36.5	3.8	130	2332.5	2161.8	590	0.33	577	1177	390	.00218	.852	45	82	0.3	2.0
46	37.2	2.5	60	2336.2	2155.0	520	0.34	508	1104	377	.00247	.934	15	11	0.04	0.5
47	39.0	.3	60	2345.6	2143.5	520	0.36	507	1103	398	.00247	.983	10.5	6	0.02	0.0
48	36.9	1.4	60	2334.6	2149.2	520	0.35	508	1104	382	.00247	.943	9	3	0.04	0.0
49	36.4	2.9	110	2332.0	2157.1	570	0.34	557	1157	388	.00226	.877	7.5	5	0.02	0.0
50	36.1	3.8	130	2330.4	2161.8	590	0.33	577	1177	388	.00218	.847	24	49	0.59	1.0
51	35.8	4.2	210	2328.9	2163.9	670	0.33	656	1255	409	.00192	.787	36	70	0.3	1.5
52	36.1	4.1	330	2330.4	2163.3	790	0.33	773	1363	447	.00163	.729	72	144	0.59	4.0
53	36.5	4.0	210	2332.5	2162.8	670	0.33	656	1255	415	.00192	.797	60	130	0.59	3.5
54	38.0	3.5	100	2340.3	2160.2	560	0.34	547	1146	390	.00230	.898	24	50	0.2	1.5
55	38.0	2.3	60	2340.3	2153.9	520	0.35	508	1104	383	.00247	.947	12	13	0.04	0.5
56	36.9	.8	55	2334.6	2146.1	515	0.35	503	1099	384	.00249	.955	6	2	0.02	0.0
57	38.1	1.0	40	2340.9	2147.2	500	0.35	488	1082	383	.00257	.982	9	9	0.04	0.0
58	37.3	1.6	70	2336.7	2150.3	530	0.35	518	1115	387	.00242	.937	9	13	0.1	0.0
59	37.3	2.3	120	2336.7	2153.9	580	0.34	567	1166	400	.00222	.888	15	30	0.1	1.0
60	37.9	2.2	115	2339.8	2153.4	575	0.35	561	1161	402	.00224	.900	24	48	0.2	1.3
61	39.2	1.9	80	2346.6	2151.9	540	0.35	527	1125	398	.00238	.949	21	33	0.1	1.0
62	39.5	1.1	55	2348.2	2147.7	515	0.36	502	1096	395	.00250	.985	12	10	0.1	0.5
63	38.8	.3	50	2344.5	2143.5	510	0.36	497	.092	394	.00251	.990	9	3	0.04	0.0
64	38.1	---	55	2340.9	------	515	----	---	----	---	------	(.970)	9	5	0.02	0.0
65	37.7	---	45	2338.8	------	505	----	---	----	---	------	(.970)	9	7	0.02	0.0

APPENDIX I
(Continued)
EXHAUST TRAVERSE DATA
TF-30-P1 Engine
NAFEC Reading No. 14 24 January 74
IDLE POWER

Position	P_{T_8} (in.H_2O)	P_{S_8} (in.H_2O)	T_{T_8} (°F)	P_o (Abs.) (lb./ft.^{2})	P_s (Abs.) (lb./ft.^{2})	T_{T_8} (Abs.) (°R)	Mach No. (M)	Stream Temp. T_S (°R)	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV $\left(\frac{\text{Slugs}}{\text{ft.}^2 \text{ sec.}}\right)$	THC PPM_c Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
66	---	---	30	2210.9	------	490	----	---	-----	---	-------	(.970)	9	4	0.02	0.0
67	40.9	---	---	2355.5	------	----	----	---	----	---	-------	(.970)	6	0	0.02	0.0
68	38.3	3.0	140	2341.9	2157.6	600	0.34	586	1186	408	.00215	.877	12	20	0.08	0.3
69	36.0	4.5	360	2329.9	2165.4	820	0.33	803	1388	452	.00157	.710	45	117	0.71	2.5
70	34.4	5.2	540	2321.5	2169.1	1000	0.31	981	1534	480	.00129	.620	108	287	1.12	6.5
71	34.6	5.7	610	2322.6	2171.7	1070	0.31	1050	1587	494	.00121	.596	162	404	1.50	9.5
72	34.1	5.8	610	2320.0	2172.2	1070	0.31	1050	1588	489	.00121	.591	165	428	1.45	10.5
73	33.3	6.1	600	2315.8	2173.8	1060	0.30	1041	1580	478	.00122	.582	168	428	1.54	10.5
74	33.6	6.0	610	2317.4	2173.3	1070	0.30	1050	1588	483	.00121	.583	180	455	1.41	10.5
75	35.1	5.5	560	2325.2	2170.7	1020	0.32	1000	1549	488	.00127	.618	168	455	1.45	10.0
76	35.6	4.8	200	2327.8	2167.0	750	0.32	735	1328	427	.00172	.735	90	218	0.80	5.0
77	37.1	3.4	110	2335.6	2159.7	570	0.34	557	1157	389	.00226	.880	31.5	53	0.17	1.5
78	38.0	1.7	65	2340.3	2150.8	525	0.35	512	1109	383	.00245	.949	16.5	16	0.08	0.5
79	30.8	---	---	2302.8	------	----	----	----	----	---	-------	(.970)	12	6	0.02	0.0
80	38.2	2.3	90	2341.4	2153.9	580	0.35	537	1135	395	.00234	.923	18	15	0.13	0.5
81	36.3	4.0	240	2331.5	2162.8	700	0.33	685	1282	423	.00184	.778	34.5	67	0.25	1.75
82	35.5	4.8	390	2327.3	2167.0	850	0.32	833	1414	454	.00152	.689	69	159	0.67	4.0
83	35.5	5.3	550	2327.3	2169.6	1010	0.32	990	1542	491	.00128	.627	123	293	1.17	8.0
84	35.1	5.5	610	2325.2	2170.7	1070	0.31	1049	1587	500	.00121	.603	150	404	1.54	11.0
85	34.4	5.7	610	2321.5	2171.7	1070	0.31	1050	1587	493	.00121	.594	174	435	1.50	11.5
86	34.7	5.5	610	2323.1	2170.7	1070	0.31	1049	1587	497	.00121	.599	195	467	1.61	11.5
87	35.6	5.1	610	2327.8	2168.6	1070	0.32	1049	1586	507	.00121	.612	183	454	1.61	11.2
88	35.9	4.6	400	2329.4	2166.0	860	0.32	842	1422	461	.00150	.691	123	298	1.00	7.2
89	37.2	3.1	160	2336.2	2158.1	620	0.34	606	1206	409	.00208	.848	54	113	0.47	3.0
90	39.2	.8	60	2346.6	2146.1	520	0.36	507	1103	397	.00247	.980	21	28	0.13	0.8

SET 1422 03 0275

APPENDIX I
(Continued)
EXHAUST TRAVERSE DATA
TF-30-P1 Engine
NAFEC Reading No. 14 24 January 74
IDLE POWER

Position	P_{T_S} (in.H_2O)	P_{S_S} (in.H_2O)	T_{T_S} (°F)	P_o (Abs.) (lb./ft.^{2})	P_s Abs. (lb./ft.^{2})	T_{T_S} (Abs.) (°R	Mach No. M	Stream Temp. T_S °R	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV Slugs (ft.^{2} sec.)	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
91	37.3	---	---	2336.7	------	----	----	----	----	---	------	(.990)	12	7	0.08	0.5
92	36.8	3.2	130	2334.1	2158.6	590	0.34	577	1177	396	.00244	.966	18	28	0.13	0.8
93	35.9	4.2	240	2329.4	2163.9	700	0.33	685	1283	419	.00184	.771	33	71	0.34	2.0
94	35.7	4.8	420	2328.3	2167.0	880	0.32	862	1438	463	.00147	.679	69	167	0.77	4.5
95	35.8	5.0	590	2328.9	2168.0	1050	0.32	1029	1571	505	.00123	.621	129	344	1.25	9.0
96	36.3	5.0	620	2331.5	2168.0	1080	0.32	1058	1593	516	.00120	.617	150	422	1.61	12.0
97	35.6	5.0	520	2327.8	2168.0	980	0.32	960	1518	487	.00132	.641	174	404	1.41	10.0
98	35.7	4.6	420	2328.3	2166.0	880	0.32	862	1438	465	.00147	.681	141	310	0.96	7.0
99	37.2	3.9	280	2336.1	2162.3	740	0.33	724	1318	441	.00174	.768	84	183	0.71	5.0
100	39.9	2.3	100	2350.3	2153.9	560	0.36	546	1145	407	.00230	.936	33	61	0.25	2.0
101	39.1	---	---	2346.1	------	----	----	----	----	---	------	(.970)	15	10	0.02	0.5
102	37.3	---	---	2336.7	------	----	----	----	----	---	------	(.970)	15	12	0.08	0.5
103	36.9	2.6	140	2334.6	2155.5	600	0.34	586	1186	403	.00214	.864	18	30	0.17	1.0
104	36.6	3.6	300	2332.0	2159.7	700	0.33	743	1336	445	.00169	.754	42	91	0.42	2.8
105	36.0	3.9	420	2329.9	2162.3	880	0.33	861	1438	472	.00146	.691	72	188	0.72	5.5
106	36.3	4.0	440	2331.5	2162.8	900	0.33	881	1454	479	.00143	.686	102	256	0.94	7.5
107	35.3	3.9	280	2326.2	2162.3	740	0.32	725	1319	428	.00174	.746	81	159	0.63	4.8
108	36.0	3.3	170	2329.9	2159.2	630	0.33	616	1216	403	.00204	.824	42	73	0.32	2.3
.09	39.4	2.4	95	2347.7	2154.5	555	0.35	542	1140	402	.00232	.933	28.5	47	0.21	1.5
110	41.6	---	---	2359.1	------	----	----	----	----	---	------	(.970)	12	8	0.02	0.5
111	37.7	---	---	2338.8	------	----	----	----	----	---	------	(.970)	10.5	7	0.02	0.5
112	37.9	---	---	2339.8	------	----	----	----	----	---	------	(.900)	15	21	0.11	0.8
113	36.6	2.1	180	2333.0	2152.9	640	0.34	625	1225	418	.00201	.839	24	51	0.23	1.5
114	35.8	2.3	190	2328.9	2153.9	650	0.34	638	1235	415	.00198	.821	30	69	0.25	2.0
115	35.3	2.0	100	2326.2	2152.4	560	0.34	548	1147	384	.00229	.881	22.5	41	0.17	1.3
116	36.3	---	---	2331.5	------	----	----	----	----	---	------	(.900)	12	11	0.08	0.5
117	40.1	---	---	2351.3	------	----	----	----	----	---	------	(.970)	10.5	7	0.02	0.3
118	29.1	---	---	2293.9	------	----	----	----	----	---	------	(.970)	9	4	0.02	0.3
119	33.1	---	---	2314.8	------	----	----	----	----	---	------	(.970)	10.5	9	0.02	0.5
120	27.1	---	---	2283.4	------	----	----	----	----	---	------	(.970)	9	6	0.02	0.5

APPENDIX I

EXHAUST TRAVERSE DATA

TF-30-P1 Engine

NAFEC Reading No. 15 25 January 74

APPROACH POWER

Average Engine Parameters during Reading No. 15 Approach Power

Air Inlet Dry Bulb Temperature - 43.6°F
Air Inlet Wet Bulb Temperature - 39.7°F
P_{T_7} - 9.40 in. Hg.
P_{T_4} - 159 in. Hg.

CIP_{total} - 30.17 in. HgA
CIP_{static} - 53.88 in. H_2O
Barometric Pressure - 30.362 in. Hg.

NOTE: Some data are missing. Numbers in parentheses have been estimated based on nozzle symmetry.

Position	P_{T_8} (in. Hg)	P_{S_8} (in.H_2O)	T_{T_8} (°F)	P_o (Abs.) (lb./ft.^{2})	P_s (Abs.) (lb./ft.^{2})	T_{T_8} (Abs.) (°R)	Mach No. (M)	Stream Temp. T_S (°R)	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV Slugs / (ft.^{2} sec.)	THC PPM$_c$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
1	9.6	4.6	85	2819.8	2164.9	545	0.63	505	1101	690	.0025	1.73	7.5	5	.13	1.0
2	9.5	12.8	220	2812.8	2207.7	680	0.60	634	1234	739	.0020	1.48	9	14	.04	2.5
3	9.2	18.8	520	2791.6	2239.0	980	0.57	920	1486	848	.0014	1.19	15	77	.25	11.8
4	9.3	23.1	700	2798.6	2261.5	1160	0.56	1091	1619	907	.0012	1.09	27	159	2.03	28
5	9.1	25.8	670	2784.5	2275.6	1130	0.55	1067	1600	872	.0012	1.05	30	179	2.01	30.5
6	8.9	26.9	660	2770.3	2281.3	1120	0.53	1059	1595	852	.0013	1.11	30	174	2.01	30
7	8.8	27.0	660	2763.3	2281.8	1120	0.53	1060	1595	846	.0013	1.10	30	170	2.03	29
8	9.0	26.1	660	2777.4	2277.1	1120	0.54	1058	1594	862	.0013	1.12	30	174	1.98	28.5
9	9.2	24.0	660	2791.6	2266.2	1120	0.55	1055	1592	882	.0013	1.15	31.5	191	1.98	28
10	9.2	20.6	440	2791.6	2248.4	900	0.57	846	1425	805	.0015	1.21	24	125	1.59	18
11	9.1	16.2	230	2784.5	2225.5	690	0.58	647	1246	717	.0020	1.43	16.5	48	.71	8
12	9.4	10.7	140	2805.7	2196.7	600	0.60	559	1159	698	.0023	1.61	12	17	.15	2.8
13	4.8	1.4	60	2480.4	2148.2	520	0.46	499	1095	501	.0025	1.25	9	6	.13	1.4
14	9.8	4.1	90	2834.0	2162.3	550	0.63	509	1105	701	.0025	1.75	6	4	.03	0.8
15	9.6	11.2	230	2819.8	2199.4	690	0.61	643	1242	754	.0020	1.51	6	15	.08	2.9

SET 1422 03 0275

SET 1422 93 0275

APPENDIX I

(Continued)

EXHAUST TRAVERSE DATA

TF-30-P1 Engine

NAFEC Reading No. 15 25 January 74

APPROACH POWER

Position	P_{T_8} (in. Hg)	P_{S_8} (in. H_2O)	T_{T_8} (°F)	P_D ($lb./ft.^2$)	P_S (Abs.) ($lb./ft.^2$)	T_{S_8} (Abs. °R)	Mach No. (M_8)	Stream Thrust Factor ($\frac{P_S}{P_D}$)	Speed of Sound a_8 (ft./sec.)	Velocity V_8 (ft./sec.)	Density ρ_8 ($slugs/ft.^3$)	$\left(\frac{slugs}{ft.^2 \cdot sec.}\right)$	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
41	9.0	22.0	500	2777.4	2255.7	960	0.55	804	1474	816	.0015	1.22	12	71.7	1.08	10.8
42	9.3	22.6	670	2798.6	2258.9	1130	0.58	1083	1591	909	.0012	1.09	18	117.3	1.66	29
43	9.2	21.6	550	2791.6	2253.7	1010	0.56	950	1510	848	.0014	1.19	15	124	1.70	28
44	9.4	19.5	390	2805.7	2242.7	850	0.52	747	1383	746	.0016	1.27	12	79	1.37	17.5
45	9.3	16.5	250	2798.6	2227.0	710	0.48	603	1264	734	.0020	1.47	10.5	50	.59	9.7
46	9.4	10.9	110	2805.7	2197.8	570	0.40	532	1130	679	.0024	1.63	6	15	.13	2.5
47	10.1	3.2	90	2855.2	2157.6	550	0.65	508	1104	713	.0025	1.74	6	4	.30	1.0
48	9.4	6.8	130	2805.7	2176.4	590	0.61	549	1148	704	.0023	1.62	6	7	.11	1.7
49	9.2	12.3	200	2791.6	2205.1	600	0.59	617	1217	719	.0021	1.51	7.5	19	.23	4.3
50	9.1	16.0	200	2784.5	2224.4	660	0.58	619	1219	702	.0021	1.47	7.5	21	.85	6.8
51	9.2	17.8	210	2791.6	2233.8	670	0.57	630	1220	705	.0021	1.48	9	40	.56	8.8
52	9.3	17.7	210	2798.6	2233.3	670	0.58	629	1220	709	.0021	1.48	15.5	70	1.17	19.7
53	9.2	17.2	300	2791.6	2230.7	760	0.58	713	1308	753	.0019	1.36	9	54	.84	14.2
54	9.4	15.0	135	2805.7	2219.2	595	0.59	559	1156	691	.0023	1.57	6	17	.17	4.4
55	9.4	10.8	110	2805.7	2197.3	570	0.60	532	1231	741	.0020	1.48	6	8	.08	2.1
56	9.3	5.2	100	2798.6	2169.0	560	0.61	521	1118	688	.0024	1.65	6	4	.03	1.0
57	9.4	4.4	110	2805.7	2161.8	570	0.62	529	1127	700	.0024	1.68	6	7	.08	1.5
58	9.3	8.5	130	2798.6	2185.3	590	0.60	550	1159	695	.0023	1.60	6	7	.08	1.8
59	9.4	10.5	200	2805.7	2195.7	600	0.60	559	1159	698	.0023	1.61	6	17	.13	3.9
60	9.4	10.5	210	2805.7	2195.7	670	0.60	625	1224	738	.0021	1.55	7.5	26	.30	6.3
61	9.5	9.6	140	2812.8	2191.0	600	0.61	559	1158	705	.0023	1.62	6	18	.25	4.5
62	9.4	7.1	100	2805.7	2177.9	560	0.61	521	1118	685	.0024	1.64	6	7	.13	1.8
63	9.3	3.3	80	2798.6	2158.1	540	0.62	501	1097	681	.0025	1.70	6	4	.03	1.0
64	9.2	1.4	90	2791.6	2148.2	550	0.62	510	1107	690	.0025	1.71	6	5	.02	1.2
65	9.6	----	70	2819.8	------	530	----	----	----	----	------	(1.69)	6	5	.04	1.2
66	5.0	----	50	2494.5	------	510	----	----	----	----	------	(1.69)	6	4	.03	1.2
67	9.6	----	---	2819.8	------	----	----	----	----	----	------	(1.69)	9	4	.17	1

SEE 1402 03 0225

APPENDIX I
(Continued)
EXHAUST TRANSIENT DATA
TF-30-P1 Engine
NAFEC Reading No. 15 25 January 74
APPROACH POWER

Position	P_{T_2} (lbs. sq)	P_{S_2} (lbs. sq)	T_{T_2} °R	T_{S_2} (°F)	T_{T_2} (°F)	T_{S_2} °R	T_{T_2} °R	P_{T_2}	T_{T_2} °R	Velocity (ft/sec)	W_{a_2} (lbs/sec)	W_f (lbs/hr)	THC PPM$_c$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
68	9.6	12.1	190	2819.8	2206.1	650	0.60	606	1200	729	.0021	1.53	9	9	.03	1.5
69	9.2	18.6	360	2791.6	2238.0	920	0.57	864	1440	823	.0033	1.23	15	61.2	.63	9.4
70	9.2	22.6	650	2791.6	2258.9	1110	0.56	1045	1584	885	.0033	1.15	22.5	131	1.70	22
71	9.2	25.5	685	2791.6	2274.0	1145	0.55	1080	1613	883	.0032	1.08	27	167	1.94	28
72	9.0	26.6	660	2777.4	2279.8	1120	0.54	1059	1584	859	.0033	1.12	27	167	2.01	27.5
73	8.8	26.7	660	2763.3	2280.3	1120	0.53	1060	1585	858	.0033	1.10	25.5	152	1.82	27.5
74	9.0	25.7	660	2777.4	2275.1	1120	0.54	1058	1584	863	.0033	1.12	28.5	167	1.82	27
75	9.2	24.0	650	2791.6	2266.2	1110	0.55	1046	1584	878	.0033	1.14	30	167	1.90	27
76	9.2	20.1	420	2791.6	2245.8	880	0.57	823	1499	798	.0036	1.28	21	104	1.25	18
77	9.0	14.6	180	2777.4	2217.1	640	0.58	600	1299	692	.0022	1.32	13.5	39	.42	6.3
78	9.3	7.7	110	2798.6	2181.1	570	0.61	531	1129	686	.0026	1.65	10.5	8	.08	2
79	1.5	----	---	2247.0	-------	----	----	522	----	----	------	(1.69)	9	5	.03	1.3
80	9.5	9.7	130	2812.8	2191.5	590	0.61	548	1148	689	.0023	1.61	7.5	6	.03	1.6
81	9.2	16.7	280	2791.6	2228.1	760	0.58	696	1290	761	.0029	1.41	9	25	.17	4.1
82	9.1	20.6	470	2784.5	2248.4	930	0.56	875	1469	816	.0035	1.22	13.5	69	.84	11.5
83	9.3	23.7	660	2798.6	2264.6	1120	0.56	1055	1591	889	.0033	1.16	19.5	138	1.72	23.5
84	9.3	25.5	680	2798.6	2274.3	1140	0.55	1075	1606	888	.0032	1.07	22.5	163	2.02	27.5
85	9.2	25.5	680	2791.6	2274.0	1140	0.55	1075	1606	883	.0032	1.06	22.5	163	2.02	29
86	9.1	24.4	660	2784.5	2268.3	1120	0.55	1056	1592	875	.0033	1.14	27	166	2.10	29
87	9.4	22.0	685	2805.7	2255.7	1145	0.57	1076	1607	917	.0032	1.09	24	166	2.10	30
88	9.4	19.8	585	2805.7	2244.3	1045	0.57	980	1534	881	.0033	1.15	21	138	1.81	26.5
89	9.3	14.5	280	2798.6	2216.6	740	0.59	692	1289	757	.0019	1.44	13.5	60	.84	11.5
90	9.5	5.5	110	2812.8	2169.6	570	0.62	529	1127	700	.0024	1.68	9	14	.25	3.1
91	9.5	13.4	170	2812.8	2210.8	630	0.60	588	1188	709	.0022	1.56	6	4	0.00	1.2
92	9.3	13.4	170	2798.6	2210.8	630	0.59	589	1199	702	.0022	1.56	7.5	10	.08	2

APPENDIX I

(Continued)

EXHAUST TRAVERSE DATA

TF-30-P1 Engine

NAFEC Reading No. 15 25 January 74

APPROACH POWER

Position	P_{T_8} (in. Hg)	P_{S_8} ($in.H_2O$)	T_{T_8} ($^{\circ}F$)	P_o (Abs.) ($lb./ft.^2$)	P_s (Abs.) ($lb./ft.^2$)	T_{T_8} Abs. ($^{\circ}R$)	Mach No. (-)	Stream Temp. T_s ($^{\circ}F$)	Speed of Sound V_s (ft./sec.)	Velocity V (ft./sec.)	Density ρ ($Slugs/Ft.^3$)	ρV ($\frac{Slugs}{ft.^2\ sec.}$)	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
93	9.1	17.2	310	2784.5	2230.7	770	0.57	723	1317	754	.0018	1.36	9	29	.23	5.3
94	9.3	20.4	530	2798.6	2247.4	990	0.57	930	1494	850	.0014	1.19	13.5	79	.92	14
95	9.4	22.5	670	2805.7	2258.6	1130	0.57	1062	1597	903	.0012	1.08	18	137	1.86	26
96	9.6	23.4	710	2819.8	2263.1	1170	0.57	1099	1624	925	.0012	1.11	21	159	2.06	32
97	9.3	22.3	630	2798.6	2257.3	1090	0.56	1025	1569	883	.0013	1.15	21	152	2.10	30.5
98	9.1	19.9	500	2784.5	2244.8	960	0.56	903	1472	830	.0015	1.24	18	106	1.57	22
99	9.4	16.7	340	2805.7	2228.1	800	0.58	749	1341	783	.0017	1.33	15	69	.88	13.6
100	9.8	10.5	140	2834.0	2195.7	600	0.62	558	1157	712	.0023	1.64	*	20	.25	6.2
101	9.6	----	---	2819.8	------	----	-----	522	----	---	------	(1.69)	9	5	.04	1.6
102	9.3	----	---	2798.6	------	----	-----	522	----	---	------	(1.69)	7.5	5	.06	1.0
103	9.2	12.5	210	2791.6	2206.1	670	0.59	626	1226	724	.0021	1.52	7.5	14	.06	2.2
104	9.3	15.7	390	2798.6	2222.8	850	0.58	796	1382	807	.0016	1.29	12	65	.38	7.5
105	9.3	17.9	510	2798.6	2234.3	970	0.58	909	1478	852	.0014	1.19	12	82	1.06	15.6
106	9.4	18.4	570	2805.7	2236.9	1030	0.58	965	1522	881	.0014	1.23	15	101	1.28	20.5
107	9.2	17.5	430	2791.6	2232.2	890	0.57	835	1415	813	.0016	1.30	13.5	79	1.12	17.5
108	9.1	15.1	270	2784.5	2219.7	730	0.58	684	1281	742	.0019	1.41	10.5	39	.46	8.5
109	9.7	11.5	150	2826.9	2200.9	610	0.61	568	1168	711	.0023	1.64	9	19	.30	3.9
110	10.0	----	---	2848.1	------	----	-----	----	----	---	------	(1.69)	6	5	.02	1.3
111	9.4	----	---	2805.7	------	----	-----	----	----	---	------	(1.69)	7.5	6	.06	1.1
112	9.4	----	---	2805.7	------	----	-----	589	----	---	------	(1.56)	7.5	9	.06	1.8
113	9.2	10.3	250	2791.6	2194.7	710	0.60	663	1261	753	.0019	1.43	9	21	.17	3.8
114	9.1	10.9	300	2784.5	2197.8	760	0.59	710	1306	773	.0018	1.39	9	35	.38	6.8
115	9.0	10.0	210	2777.4	2193.1	670	0.59	626	1226	725	.0020	1.45	9	29	.40	6
116	9.2	----	---	2791.6	------	----	-----	588	----	---	------	(1.56)	9	12	.11	2.5
117	9.4	----	---	2805.7	------	----	-----	522	----	---	------	(1.69)	9	6	.08	1.1
118	5.5	----	---	2529.9	------	----	-----	522	----	---	------	(1.69)	7.5	5	.03	0.9
119	6.7	----	---	2614.7	------	----	-----	522	----	---	------	(1.69)	9	5	.02	1.0
120	3.2	----	---	2367.2	------	----	-----	522	----	---	------	(1.69)	7.5	7	.02	0.9

SET 1422 03 0275

SCOTT ENVIRONMENTAL TECHNOLOGY, INC.

SET 1422 03 0275

APPENDIX I

EXHAUST EMISSION DATA

YF-75-PW Engine

NAVTC Reading No. 17 31 January 74

MAXIMUM CONTINUOUS POWER

Average Engine Parameters during Reading No. 17 Maximum Continuous Power

Air Inlet Dry Bulb Temperature - 54.7°F
Air Inlet Wet Bulb Temperature - 50.5°F

P_{T_7} - 26.75 in. Hg.

P_{T_4} - 355 in. Hg.

CIP_{total} - 29.53 in. Hg A

CIP_{static} - 33.9 - in. H 0

Barometric Pressure - 29.39 in. Hg

NOTE: Some data are missing.
Numbers in parentheses have been estimated based on nozzle symmetry.

Position	P_{T_3} (in. Hg)	P_{S_2} (in. H_2O)	T_{T_2} °F	P_{T_2} (lbs/ft.^{2})	P_{S_2} (lbs/ft.^{2})	T_{T_3} °R	M_2	Stream Specific Weight γ (lbs/ft.^{3})	Velocity V (ft/sec.)	Flowrate Q (lbs./sec.)	Mass Flow W (lbs./sec.)	THC PPM$_c$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
1	26.6	2.25	200	3989.7	2267.5	660	0.94	562	1161	1087	.0024	2.61	16.5	2	0.00	0.0
2	26.6	2.50	(475)	3989.7	2285.2	(935)	0.93	797	1383	1286	.0017	2.19	12.0	4	.21	3.3
3	27.0	3.75	820	4018.0	2373.6	1280	0.90	1101	1628	1485	.0013	1.90	12.0	20	1.61	50.0
4	27.3	4.50	1000	4039.2	2426.7	1460	0.88	1262	1741	1561	.0011	1.70	10.5	40	3.07	95.0
5	27.1	5.00	970	4025.1	2462.0	1430	0.87	1242	1727	1500	.0012	1.80	10.5	42	2.95	107.5
6	26.6	5.50	950	3989.7	2497.4	1410	0.85	1233	1731	1457	.0012	1.75	10.5	41	3.01	100.0
7	26.0	5.50	940	3947.3	2497.4	1400	0.86	1228	1719	1436	.0012	1.72	10.5	42	2.97	97.5
8	26.5	5.50	950	3982.7	2497.4	1410	0.85	1236	1721	1454	.0012	1.75	10.5	45	2.81	95.0
9	27.2	5.25	960	4032.2	2479.7	1420	0.86	1236	1722	1487	.0012	1.78	10.5	46	2.90	95.0
10	26.2	4.25	680	3961.4	2409.0	1140	0.87	989	1561	1347	.0014	1.89	10.5	30	2.30	72.5
11	25.6	3.25	380	3919.0	2338.3	840	0.89	725	1319	1137	.0019	2.24	12.0	13	.95	28.0
12	26.1	2.75	240	3954.4	2302.9	700	0.91	600	1200	1043	.0022	2.41	12.0	5	.38	9.3
13	----	----	50	------	------	510	----	----	----	----	----	------	(7.561)	12.0	2	.13	.8
14	25.4	1.50	190	3904.9	2214.5	650	0.94	553	1152	1081	.0023	2.49	12.0	2	.08	1.2
15	26.1	2.40	440	3954.4	2278.7	900	0.92	769	1358	1255	.0019	2.33	12.0	5	.41	11.5

APPENDIX I
(Continued)
EXHAUST TRAVERSE DATA
TF-30-P1 Engine
NAFEC Reading No. 17 31 January 74
MAXIMUM CONTINUOUS POWER

Position	P_{T_8} (in. Hg)	P_{S_8} (in.H_2O)	T_{T_8} (°F)	P_o (Abs.) (lb./ft.^{2})	P_s (Abs.) (lb./ft.^{2})	T_{T_8} (Abs. °R)	Mach No. (M)	Stream Temp. T_s (°R)	Speed of Sound a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	ρV^2 (lb./ft.^{2} sec.)	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
16	26.7	3.25	770	3996.8	2338.3	1230	0.91	1055	1591	1449	.0013	1.88	12.0	18	1.61	50.0
17	27.6	4.25	960	4060.5	2409.0	1420	0.90	1223	1713	1538	.0011	1.69	12.0	36	2.97	94.0
18	27.7	5.00	960	4067.5	2462.0	1420	0.88	1230	1718	1510	.0012	1.81	12.0	39	3.13	107.5
19	26.6	5.50	920	3989.7	2497.4	1380	0.85	1207	1702	1441	.0012	1.73	12.0	41	3.06	100.0
20	26.3	5.50	920	3968.5	2497.4	1380	0.84	1209	1703	1433	.0012	1.72	12.0	42	2.86	95.0
21	27.0	5.50	940	4018.0	2497.4	1400	0.85	1222	1713	1462	.0012	1.75	6.0	51	2.93	95.0
22	26.7	5.00	940	3996.8	2462.0	1400	0.86	1219	1710	1475	.0012	1.77	10.5	50	3.01	95.0
23	26.8	4.00	700	4003.9	2391.3	1160	0.89	1001	1550	1381	.0014	1.93	12.0	35	2.49	79.0
24	26.0	3.25	445	3947.3	2338.3	905	0.90	779	1368	1229	.0018	2.21	12.0	18	1.24	38.0
25	26.5	2.50	250	3982.7	2285.2	710	0.93	606	1206	1119	.0022	2.46	12.0	6	.34	11.3
26	----	----	40	------	------	500	----	----	----	----	----	(2.56)	12.0	4	.08	1.5
27	25.6	2.50	300	3919.0	2285.2	700	0.91	651	1250	1142	.0020	2.28	12.0	5	.25	9.0
28	26.7	2.75	550	3996.8	2302.9	1010	0.92	863	1439	1330	.0016	2.13	12.0	13	1.08	35.0
29	26.4	3.75	825	3975.6	2373.6	1285	0.89	1109	1631	1454	.0012	1.75	12.0	24	2.13	68.0
30	26.8	4.50	915	4003.9	2426.7	1375	0.88	1191	1691	1484	.0012	1.78	12.0	35	2.76	96.0
31	26.9	5.00	935	4010.9	2462.0	1395	0.87	1213	1707	1477	.0012	1.77	12.0	39	2.93	99.0
31x	27.0	5.00	950	4018.0	2462.0	1410	0.87	1226	1715	1487	.0012	1.78	12.0	42	3.01	103.0
32	27.1	5.00	965	4025.1	2462.0	1425	0.87	1238	1724	1498	.0012	1.80	12.0	44	3.05	108.0
33	27.3	4.50	910	4039.2	2426.7	1370	0.89	1186	1686	1493	.0012	1.79	12.0	49	3.01	103.0
34	26.2	3.75	600	3961.4	2373.6	1060	0.89	916	1482	1316	.0015	1.97	12.0	29	1.89	64.0
35	26.1	3.00	290	3954.4	2320.6	750	0.91	644	1243	1128	.0021	2.37	12.0	12	.83	24.0
36	27.3	1.75	130	4039.2	2232.2	590	0.96	498	1093	1051	.0026	2.73	12.0	4	.21	6.0
37	25.3	2.00	220	3897.8	2249.9	680	0.92	581	1181	1090	.0023	2.51	12.0	2	.13	4.0
38	25.6	2.60	420	3982.7	2292.3	880	0.93	751	1343	1242	.0018	2.24	12.0	7	.50	17.0
39	25.9	3.00	610	3940.2	2320.6	1070	0.90	920	1486	1363	.0015	2.01	12.0	15	1.24	41.0
40	25.8	3.75	685	3933.1	2373.6	1145	0.88	991	1542	1360	.0014	1.90	12.0	19	1.53	54.0
41	26.1	4.25	860	3954.4	2409.0	1520	0.87	1319	1780	1553	.0011	1.71	12.0	29	2.29	73.0

SET 1422 03 0275

APPENDIX I
(Continued)
EXHAUST TRAVERSE DATA
TF-30-P1 Engine
NAFEC Reading No. 17 11 January 74
MAXIMUM CONTINUOUS POWER

Position	P_{t_s} (in. Hg)	P_{s_s} (in. H_2O)	T_s °F	F_s (ft.²)	F_n (ft.²)	T_{t_s} °R	ΔP	T_s °R	V_s (ft./sec.)	W_a (lb./min.)	ρ_s (lb./ft.³)	W_f (lb./hr.)	THC PPM$_c$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
42	26.9	4.50	970	4010.9	2426.7	1430	0.88	1239	1324	1316	.0011	1.67	12.0	40	2.97	98.0
43	26.7	4.50	960	3996.8	2426.7	1420	0.88	1231	1707	1699	.0012	1.80	12.0	41	2.77	93.0
44	27.1	4.00	750	4025.1	2391.3	1210	0.90	1063	1582	1618	.0013	1.84	12.0	32	2.18	68.0
45	26.3	3.25	450	3968.5	2338.3	910	0.90	782	1370	1338	.0017	2.11	12.0	19	1.20	38.0
46	26.2	2.25	210	3961.4	2267.5	670	0.93	573	1171	1089	.0023	2.50	12.0	6	.10	10.0
47	2.6	----	50	2292.3	-------	510	----	----	----	----	------	(2.56)	12.0	2	.04	2.0
48	25.6	2.75	250	3919.0	2302.9	710	0.91	610	1310	1046	.0022	2.41	12.0	3	.13	--
49	25.6	2.75	350	3919.0	2302.9	810	0.91	696	1292	1271	.0019	2.42	12.0	7	.50	17.0
50	25.4	3.00	420	3904.9	2320.6	880	0.90	758	1349	1299	.0018	2.38	12.0	9	.58	22.0
51	26.2	3.25	680	3961.4	2338.3	1140	0.90	980	1535	1384	.0016	1.94	12.0	18	1.40	47.0
52	26.2	3.50	750	3961.4	2356.0	1210	0.90	1043	1582	1516	.0013	1.84	12.0	26	1.97	65.0
53	26.1	3.25	540	3954.4	2338.3	1000	0.90	860	1437	1295	.0016	2.07	12.0	18	1.24	48.0
54	25.6	3.00	340	3919.0	2320.6	800	0.90	689	1286	1156	.0020	2.31	12.0	10	.58	26.0
55	25.5	2.75	215	3911.9	2302.9	675	0.90	580	1180	1067	.0023	2.45	12.0	7	.25	12.0
56	25.9	.75	90	3940.2	2161.5	550	0.97	463	1054	1021	.0027	2.76	12.0	4	.04	5.0
57	25.8	.75	200	3933.1	2161.5	660	0.97	556	1155	1117	.0023	2.57	12.0	3	.08	7.0
58	25.3	2.75	270	3897.8	2302.9	730	0.90	628	1228	1106	.0021	2.32	12.0	5	.17	9.0
59	25.8	2.50	415	3933.1	2285.2	875	0.92	749	1361	1279	.0018	2.21	12.0	10	.67	22.0
60	25.9	2.75	360	3940.2	2302.9	820	0.91	703	1299	1184	.0019	2.25	12.0	10	.71	24.0
61	25.7	2.75	230	3926.1	2302.9	690	0.91	592	1193	1083	.0021	2.49	12.0	6	.33	14.0
62	25.3	2.50	170	3897.8	2285.2	630	0.91	541	1139	1035	.0023	2.59	12.0	3	.13	4.0
63	24.4	----	60	3834.1	-------	520	----	----	----	----	------	(2.56)	12.0	2	.04	2.0
64	19.4	----	90	3480.5	-------	550	----	----	----	----	------	(2.56)	12.0	3	.13	5.0
65	18.5	----	70	3416.8	-------	530	----	----	----	----	------	(2.56)	12.0	3	.13	4.0
66	.8	----	40	2165.0	-------	500	----	----	----	----	------	(2.56)	12.0	3	.04	2.0
67	26.3	----	---	3968.5	-------	----	----	----	----	----	------	(2.56)	12.0	2	.04	2.0

SET 1422 01 0275

APPENDIX I
(Continued)
EXHAUST TRAVERSE DATA
TF-30-P1 Engine
NAFEC Reading No. 17 31 January 74
MAXIMUM CONTINUOUS POWER

Position	P_{T_S} (in. Hg)	P_{S_S} (in.H_2O)	T_{T_S} (°F)	P_o (Abs.) (lb./ft.^{2})	P_s (Abs.) (lb./ft.^{2})	T_{T_S} (Abs. °R)	Mach No. (M)	Stream Temp. T_s (°R)	Speed of Sound V_a (ft./sec.)	Velocity V (ft./sec.)	Density ρ (Slugs/ft.^{3})	$\frac{\rho V}{\text{Slugs}/(\text{ft.}^2\ \text{sec.})}$	THC PPM$_c$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
68	26.2	2.50	390	3961.4	2285.2	850	0.92	726	1320	1219	.0018	2.19				
69	26.1	3.50	690	3954.4	2356.0	1150	0.89	992	1543	1378	.0014	1.93	9.0	.17	1.0	2.19
70	26.4	4.25	930	3975.6	2409.0	1390	0.88	1204	1700	1492	.0012	1.79	9.0	13	1.16	34.0
71	26.7	5.00	980	3996.8	2462.0	1440	0.88	1254	1735	1496	.0011	1.65	9.0	27	2.57	75.0
72	26.6	5.50	960	3989.7	2497.4	1420	0.85	1242	1727	1462	.0012	1.75	12.0	39	3.16	97.0
73	26.3	5.50	955	3968.5	2497.4	1415	0.85	1239	1725	1452	.0012	1.74	12.0	38	3.12	108.0
74	26.3	5.50	960	3968.5	2497.4	1420	0.84	1244	1728	1454	.0012	1.74	12.0	37	3.00	105.0
75	27.0	5.00	990	4018.0	2462.0	1450	0.87	1260	1740	1508	.0011	1.66	12.0	41	3.05	103.0
76	26.1	4.25	700	3954.4	2409.0	1160	0.87	1007	1555	1357	.0014	1.90	12.0	42	3.32	105.0
77	25.5	3.00	300	3911.9	2320.6	760	0.90	655	1254	1125	.0021	2.36	12.0	28	2.41	78.0
78	25.8	2.50	200	3933.1	2285.2	660	0.92	565	1165	1067	.0024	2.56	12.0	9	.83	27.0
79	----	----	---	------	------	----	----	----	----	-----	------	(2.56)	12.0	3	.13	7.0
80	26.3	2.50	(250)	3968.5	2285.2	710	0.92	606	1206	1115	.0022	2.45	12.0	3	.00	2.0
81	25.7	3.00	500	3926.1	2320.6	960	0.90	826	1408	1264	.0016	2.03	12.0	3	.13	4.0
82	25.7	4.00	720	3926.1	2391.3	1180	0.87	1024	1568	1368	.0014	1.92	12.0	6	.46	2.03
83	26.3	4.75	940	3968.5	2444.4	1400	0.86	1219	1711	1475	.0012	1.77	12.0	14	1.33	44.0
84	27.2	5.00	970	4032.2	2462.0	1430	0.87	1242	1727	1503	.0012	1.80	12.0	27	2.65	83.0
85	27.3	5.25	980	4039.2	2479.7	1440	0.87	1252	1734	1500	.0012	1.80	12.0	34	3.21	105.0
86	26.6	5.00	1000	3989.7	2462.0	1460	0.86	1272	1747	1503	.0011	1.65	12.0	39	3.28	105.0
87	26.7	4.75	975	3996.8	2444.4	1435	0.87	1247	1730	1503	.0011	1.65	12.0	40	3.24	105.0
88	26.1	3.75	670	3954.4	2373.6	1130	0.89	977	1531	1357	.0014	1.90	12.0	40	3.28	110.0
89	26.0	3.00	300	3989.7	2320.6	760	0.92	651	1250	1144	.0021	2.40	12.0	30	2.45	110.0
90	26.0	2.50	140	3947.3	2285.2	600	0.92	513	1110	1021	.0026	2.65	12.0	10	.87	31.0
91	----	----	---	------	------	----	----	----	----	----	------	(2.56)	12.0	3	.13	7.0
92	25.4	2.75	325	3904.9	2302.9	785	0.90	675	1273	1149	.0020	2.30	12.0	2	.08	3.0
													12.0	2	.13	7.0

SET 1622 03 0215

APPENDIX I
(Continued)
EXHAUST TRAVERSE DATA
TF-30-P1 Engine
NAFEC Readline No. 17 31 January 74
MAXIMUM CONTINUOUS POWER

Position	P_{s_0} (in. Hg)	P_{s_0} (in. H$_2$O)	T_{t_0} °F	W_a (lb/sec)	W_f (lb/hr)	η_c	η_t	T_{t_5} °F	T_{t_6} °F	P_{t_6} (psia)	W_f/W_a	THC PPM$_C$ Wet	CO PPM Wet	CO_2 % Wet	NO_x PPM Wet
93	25.5	3.25	550	3911.9	2338.3	1010	0.89	872	1453	1288	.0016	2.06	12.0	9	.71	25.0
94	26.1	4.00	810	3954.4	2391.3	1270	0.88	1100	1625	1428	.0013	1.88	12.0	17	1.77	59.0
95	26.8	4.50	950	4003.9	2426.7	1410	0.88	1227	1713	1503	.0012	1.80	9.0	30	2.89	98.0
96	27.0	4.75	990	4018.0	2444.4	1450	0.87	1258	1738	1519	.0011	1.67	9.0	37	3.12	113.0
97	26.9	4.50	890	4010.9	2426.7	1350	0.88	1169	1675	1473	.0012	1.77	9.0	36	3.24	110.0
98	25.8	4.00	680	3933.1	2391.3	1140	0.87	989	1561	1367	.0014	1.89	15.0	21	1.97	68.0
99	26.0	3.25	420	3947.3	2338.3	880	0.90	758	1369	1212	.0018	2.18	6.0	13	1.04	35.0
100	26.5	2.50	200	3982.7	2285.2	660	0.91	563	1163	1079	.0024	2.59	6.0	4	.30	8.0
101	----	----	---	------	------	----	----	----	----	----	------	(2.56)	3.0	2	.21	2.0
102	25.5	----	---	3911.9	------	----	----	----	----	----	------	(2.56)	3.0	3	.13	4.0
103	25.4	2.75	200	3904.9	2302.9	660	0.90	567	1167	1056	.0024	2.53	6.0	5	.37	13.0
104	25.8	3.00	200	3933.1	2320.6	660	0.90	568	1167	1053	.0024	2.53	6.0	12	1.09	34.0
105	26.1	3.50	710	3954.4	2356.0	1170	0.88	1009	1556	1390	.0014	1.95	6.0	19	1.73	57.0
106	26.2	3.50	770	3961.4	2356.0	1230	0.90	1060	1595	1428	.0013	1.86	6.0	21	1.97	63.0
107	26.0	3.50	630	3947.3	2356.0	1090	0.89	940	1503	1360	.0015	2.01	6.0	21	2.09	63.0
108	25.4	3.00	380	3904.9	2320.6	840	0.90	726	1318	1181	.0019	2.24	6.0	11	.87	31.0
109	26.1	3.00	220	3954.4	2320.6	680	0.91	584	1184	1074	.0023	2.47	6.0	5	.30	8.0
110	18.1	----	---	3388.6	------	----	----	----	----	----	------	(2.56)	6.0	2	.13	2.0
111	25.6	----	---	3919.0	------	----	----	----	----	----	------	(2.56)	3.0	4	.13	6.0
112	25.9	----	---	3940.2	------	----	----	----	----	----	------	(2.42)	6.0	5	.33	11.0
113	25.8	3.00	220	3933.1	2320.6	680	0.90	585	1185	1069	.0023	2.46	6.0	7	.50	17.0
114	25.5	3.00	220	3911.9	2320.6	680	0.90	586	1186	1066	.0023	2.45	3.0	10	.53	21.0
115	25.2	3.00	220	3890.7	2320.6	680	0.89	587	1187	1059	.0023	2.44	3.0	9	.74	22.0
116	25.3	----	---	3897.8	------	----	----	----	----	----	------	(2.42)	3.0	3	.21	7.0
117	7.7	----	---	2653.0	------	----	----	----	----	----	------	(2.56)	6.0	3	.04	2.0
118	.5	----	---	2143.8	------	----	----	----	----	----	------	(2.56)	3.0	3	.08	2.0
119	.7	----	---	2157.9	------	----	----	----	----	----	------	(2.56)	3.0	3	.04	3.0
120	----	----	---	------	------	----	----	----	----	----	------	(2.56)	6.0	2	.08	2.0

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SET 1422 01 0225

SCOTT ENVIRONMENTAL TECHNOLOGY, INC.

APPENDIX II

PROBE DATA INVENTORY

30 September 1974

Probe No.	Type	Angle	Mode	NAFEC Rdg. No.	EPR	Concentrations THC ppmC	CO ppm	CO_2 %	SO_x ppm	lb./K lb. Fuel THC	CO	NO_x	A/F Calc.	A/F Meas.
1	12 Pt. Cruciform	0°	Idle	272	1.084	49.8	194	0.726	5.6	7.63	51.9	2.46	277	315
		15				50.7	185	0.649	5.1	8.67	55.2	2.50	309	
		30				55.8	180	0.601	4.8	10.3	57.9	2.54	333	
		45				53.7	178	0.664	5.0	8.99	52.0	2.40	302	
		60				51.6	181	0.680	5.4	8.44	51.7	2.53	295	
		75				51.9	194	0.730	5.7	7.91	51.6	2.49	275	
		90	↓			55.2	201	0.745	5.7	8.24	52.4	2.44	269	
2	NAFEC Diamond	0	Idle			54.9	191	0.715	5.3	8.54	51.9	2.36	281	
		15				43.5	180	0.692	5.3	7.09	50.6	2.45	291	
		30				45.6	203	0.780	6.0	6.52	50.7	2.46	258	
		45				51.1	233	0.845	6.5	6.99	53.6	2.45	237	
		60		↓		56.7	215	0.758	5.9	8.31	55.0	2.48	264	
		75		273	1.081	57.3	204	0.730	5.4	8.72	54.2	2.36	275	
		90				55.2	204	0.712	5.4	8.60	55.5	2.41	281	
		0				53.7	194	0.695	5.3	8.58	54.1	2.43	288	
		+ 2.5				55.2	194	0.691	5.3	8.87	54.4	2.44	290	
		+ 5				50.4	185	0.691	5.3	8.11	52.0	2.45	291	
		0				53.7	193	0.690	5.3	8.64	54.2	2.45	290	
		- 2.5				54.3	198	0.693	5.4	8.69	55.4	2.48	289	
		- 4.0				57.3	200	0.695	5.4	9.14	55.7	2.47	288	
		0	↓			51.9	193	0.680	5.4	8.47	55.0	2.53	295	

SEE 1422 04 0275

APPENDIX II

PROBE DATA INVENTORY

30 September 1974

Probe No.	Type	Angle	Mode	NAFEC Rdg. No.	EPR	Concentrations THC ppm-C	CO ppm	CO_2 %	NO_X ppm	Lb./K Lb. Fuel THC	CO	NO_X	A/F Calc.	A/F Meas.
3	P&W Spiral	0	Idle	273	1.081	52.8	211	0.775	---	7.58	52.9	---	259	315
		15				52.5	197	0.705	5.7	8.27	54.2	2.58	284	
		30				53.1	187	0.665	5.3	8.86	54.5	2.53	301	
		45				53.1	187	0.665	5.3	8.86	54.5	2.53	301	
		60				45.6	180	0.668	5.4	7.59	52.4	2.58	301	
		75				49.5	193	0.715	5.7	7.70	52.4	2.54	281	
		90				49.5	194	0.711	5.6	7.74	52.9	2.51	282	
		0				52.8	208	0.751	6.0	7.81	53.8	2.55	267	
1	With Center Hole	0	Idle	274	1.082	53.4	208	0.771	5.9	7.70	52.4	2.44	260	319
	12 pt. Cruciform	30				52.8	191	0.672	5.2	8.72	55.1	2.46	298	
		60				50.7	199	0.730	5.7	7.72	52.9	2.49	275	
		90				55.2	216	0.773	6.0	7.93	54.2	2.47	259	
		0				53.7	210	0.761	5.9	7.84	53.6	2.47	264	
3	With Center Hole	0	Idle			54.0	238	0.851	6.5	7.05	54.3	2.44	236	
	P&W Spiral	30				58.2	215	0.755	5.8	8.56	55.2	2.45	265	
		60				52.5	206	0.755	5.8	7.73	53.0	2.45	266	
		90				52.8	215	0.785	6.0	7.48	53.2	2.44	256	
		0				57.6	238	0.852	6.5	7.51	54.2	2.43	235	

SET 1422 03 0275

SCOTT ENVIRONMENTAL TECHNOLOGY, INC.

APPENDIX II

PROBE DATA INVENTORY

October 1975

Probe No.	Type	Angle	Mode	NAFEC Rdg. No.	Concentrations THC ppm	CO ppm	CO_2 %	NO_x ppm	Lb./K Lb. Fuel THC	CO	NO_x	A/F Calc.	A/F Meas.
3	P&W Spiral	0	Idle	275 1.081	72.9	190	0.609	4.3	13.0	59.0	2.30	321	316
		15			71.4	174	0.548	4.0	14.1	61.0	2.30	363	
		30			69.6	170	0.525	3.8	14.6	62.2	2.28	378	
		45			66.6	168	0.531	3.9	13.8	60.9	2.32	375	
		60			60.6	164	0.558	4.0	12.2	57.7	2.31	364	
		75			64.3	174	0.568	4.2	12.5	59.0	2.36	351	
		90			66.0	176	0.561	4.1	13.0	60.4	2.31	355	
2	NAFEC Diamond	90	Idle		65.7	187	0.596	4.1	12.2	60.5	2.18	334	
		75			71.4	194	0.599	4.0	13.1	62.6	2.11	333	
		60			72.0	201	0.620	4.3	12.4	60.5	2.13	311	
		45			69.6	213	0.685	4.7	11.2	60.0	2.12	291	
		30			63.0	190	0.660	4.5	10.9	57.4	2.21	312	
		15			59.1	171	0.573	4.1	11.4	57.4	2.26	347	
		0			67.2	184	0.588	4.1	12.6	60.3	2.21	339	
1	12 Pt. Cruciform	0	Idle		66.6	193	0.622	4.5	11.7	59.4	2.27	318	
		15			63.6	178	0.563	4.1	12.5	61.2	2.32	356	
		30			63.3	176	0.552	3.9	13.0	61.4	2.23	361	
		45			64.2	181	0.586	4.2	12.1	59.5	2.27	340	
		75			61.6	187	0.632	4.6	11.1	57.2	2.31	316	
		90			69.0	197	0.660	4.7	11.9	59.4	2.31	312	
1	12 Pt. Cruciform	90	High	276 1.098	51.9	179	0.697	5.5	8.29	49.9	2.52	288	312
		75	Idle		49.5	173	0.695	5.3	7.94	48.4	2.53	289	
		60			47.1	161	0.655	5.2	8.02	47.8	2.51	307	
		30			48.9	157	0.597	4.7	9.10	51.1	2.52	336	
		15			46.8	156	0.625	4.9	8.34	48.6	2.50	322	
		0			46.8	164	0.686	5.2	7.61	46.6	2.66	294	

APPENDIX II

PROBE DATA INVENTORY

3 October 1974

Probe No.	Type	Angle	Mode	NAFEC Rdg. No.	EPR	Concentrations THC ppm-C	CO ppm	CO_2 %	NO_X ppm	Lb./K Lb. Fuel THC	CO	NO_X	A/F Calc.	A/F Meas.
1	12 Pt. Cruciform	0	Higher	277	1.099	39.6	155	0.703	6.2	6.30	43.1	2.83	287	303
		15	Idle			37.8	145	0.802	5.7	5.30	35.5	2.29	253	
		30				38.1	164	0.627	5.5	6.77	50.9	2.80	321	
		45				39.9	145	0.663	6.0	6.73	42.7	2.90	305	
		60				38.4	148	0.693	6.3	6.21	41.8	2.92	292	
		75				41.1	157	0.730	6.6	6.43	42.6	2.92	277	
		90				41.7	156	0.715	6.5	6.53	42.6	2.92	283	
1	12 Pt. Cruciform	90	App.			14.1	92	0.985	16.2	1.63	18.6	5.37	208	N
		60				12.7	87	0.950	15.6	1.52	18.2	5.36	216	O
		30		278		11.7	79	0.830	13.8	1.60	18.9	5.43	247	
		0				10.0	90	0.957	16.5	1.19	18.7	5.63	214	D
2	NAFEC Diamond	0	App.			8.2	90	0.990	16.6	0.943	18.1	5.48	207	A T A
		30				10.5	91	1.04	17.7	1.15	17.4	5.56	197	
		60				12.1	97	1.06	18.0	1.30	18.2	5.54	194	
		90				11.4	88	0.988	16.8	1.31	17.7	5.55	208	
3	12 Pt. P&W Spiral	90	App.			----	85	0.835	13.5	----	20.2	5.28	246	
		60				12.1	79	0.844	14.0	1.63	18.6	5.41	243	
		30				12.6	81	0.810	13.5	1.77	19.8	5.44	253	
		0				12.3	90	0.912	15.0	1.53	19.6	5.36	225	
		15				13.2	85	0.860	14.3	1.74	19.6	5.42	241	
3	12 Pt. P&W Spiral	0	Cruise	279		----	38	1.72	52.2	----	4.43	9.99	120	154
		30				2.0	34	1.57	46.7	0.15	4.34	9.79	131	
		60				----	36	1.65	49.5	----	4.37	9.87	125	
		90				----	36	1.67	49.9	----	4.32	9.84	123	
3	12 Pt. P&W Spiral	90	MCP	280		----	20	2.00	70.5	----	2.00	11.6	103	136

*A/F of run #15

APPENDIX III

ENGINE DATA DURING TEST RUNS

NAFEC Rdg. No.	B.P. in Hg	Humidity gr/lb Dry Air	CIT °F	EPR	W_A lb/sec	$W_{F_{Corr}}$ lb/hr	$W_{F_{Obs}}$ lb/hr	$F_{G_{Corr}}$ lb.	$F_{G_{Obs}}$ lb.	N_1	N_2	C.D.T. °R	TDT °R	A/F M
14	30.27	24.0	41	1.079	76.2	870	871	878	1075.5	3572	8572	707	1357	315
15	30.26	30	40	1.312	141	2242	2230	3811	3841.5	6186	11075	908	1646	228
16	29.93	47	51	1.738	204.0	4786	4723	8263	8201	8127	12475	1097	2042	155
17	29.80	49	47	1.906	218.3	5356	5249	9898	9780	8662	12863	1157	2175	150
272	29.80	44.11	62.50	1.084	80	918	913	1068	1062	3612	8611	695.0	1380	315
273	29.79	45.86	62.00	1.081	80	918	914	1068	1062	3630	8580	695.7	1382	315
274	29.79	47.66	62.00	1.082	79	896	891	1069	1062	3589	8531	690.7	1382	319
275	30.23	23.57	48.00	1.081	76.82	874	874	1053	1062	3559	8484	689.3	1369	316
276	30.23	23.57	47.00	1.098	87.72	1013	1013	1294	1304	3904	8962	711.1	1397	312
277	30.23	23.57	48.00	1.099	96.66	1150	1150	1555	1567	4245	9378	735.3	1430	303
278	30.24	22.54	48.00	--	--	2257	2257	3836	3862	6177	11014	893.6	1655	--
279	30.24	22.54	46.50	1.681	203.5	4760	4759	8230	8270	8107	12461	1076	2059	154
280	30.24	22.54	45.00	1.853	218.6	5814	5805	9906	9928	8676	12861	1140	2199	136

B.P. = Barometric Pressure inches of mercury

Humidity = Grains per pound of dry air

CIT = Compressor inlet total temperature (^{o}F)

EPR = Engine pressure ratio

W_A = Air flow in pounds per second

$W_{F_{Corr}}$ = Fuel flow corrected to standard day conditions

$W_{F_{Obs}}$ = Actual fuel flow during the test pounds per hour

$F_{G_{Corr}}$ = Thrust corrected to standard day conditions (pounds)

$F_{G_{Obs}}$ = Actual thrust during the test

N_1 = Low speed rotor RPM

N_2 = High speed rotor RPM

CDT = Compressor discharge total temperature ^{o}R

TDT = Turbine discharge temperature ^{o}R

A/F = Air fuel ratio = $\frac{W_A\ (3600)}{W_{F_{Obs}}}$

SCOTT ENVIRONMENTAL TECHNOLOGY, INC.

END

SET 1422 03 0275